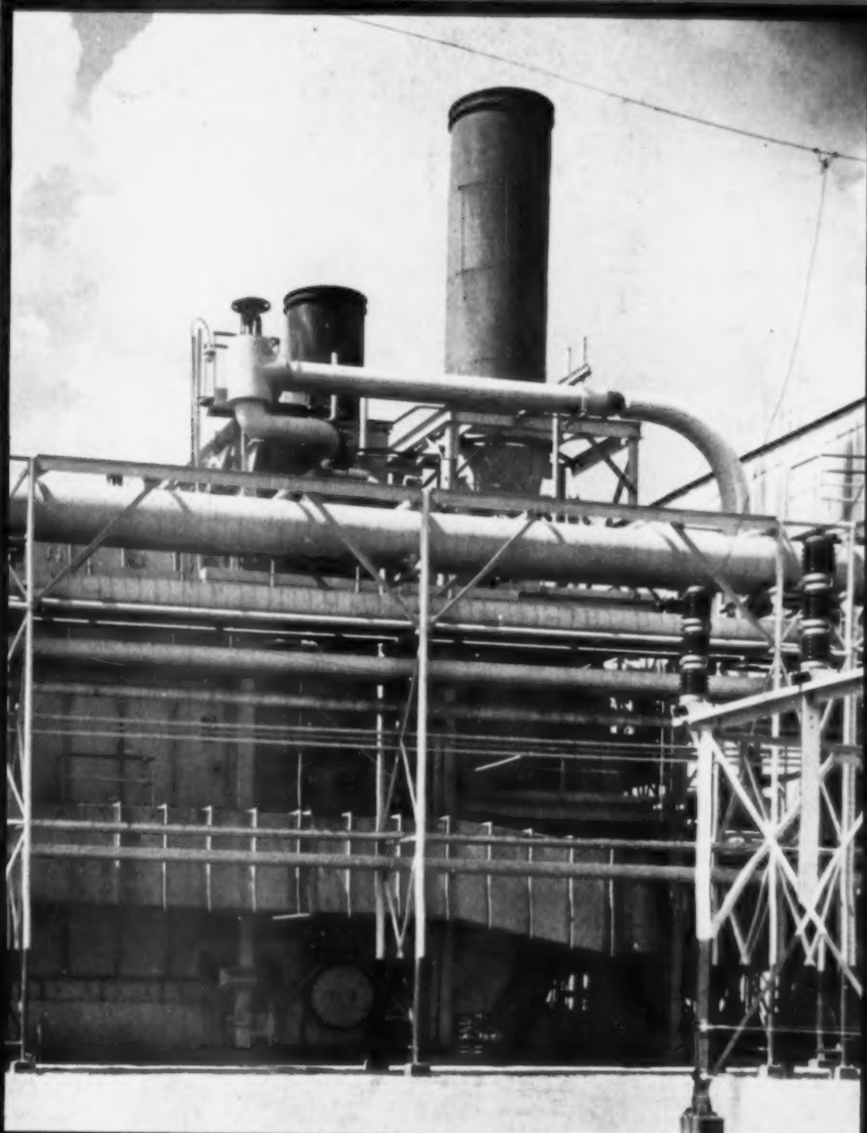
COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

March, 1947



Typical outdoor industrial power plant in the Southwest

External Deposits on Boiler Surfaces ▶

Modified Super-Regenerative Arrangement ▶

Carryover Problems and Identification of Carryover Types ▶

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FOR MARCH 1947

FEATURE ARTICLES

EDITORIALS

DEPARTMENTS

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EDITORIAL

Natural Gas to the Eastern Seaboard

After prolonged negotiations, during which a number of bids were received and rejected because of inadequacy, the War Assets Administration has finally sold the Big Inch and the Little Inch Pipe lines to the Texas Eastern Transmission Company for the delivery of natural gas from Texas fields to the Eastern Seaboard. The bid exceeded 143 million dollars which is only slightly under the wartime cost to the Government. This is quite unusual considering the very large losses sustained in the disposal of most of the Government's wartime properties. These lines, built and equipped to convey oil, will require further expenditure by the new owners to adapt them to gas pumping. Moreover, the sale requires approval by the Attorney General and a certificate of convenience and necessity by the Federal Power Commission.

Opposition offered by the coal industry, the railroads, and their respective labor organizations was undoubtedly weakened by recollection of the public's experience during the coal stoppage last fall. If so, the miners have themselves to blame, but the contentions of displacement of mine labor is discounted by increased industrial activity and export demands for coal. Comparatively speaking, the natural gas will displace only a very small percentage of the total coal burned in this region, and its use will be confined largely to residential and industrial purpose, rather than to power boilers. However, there is said to be a large surplus of supply over demand for natural gas in Texas; the pipe lines are already built; and there is a substantial market in the East; therefore, the transaction appears both logical and economically sound.

Reheat Again Being Considered

About twenty years ago reheat was popular in this country and was incorporated in the design of a number of stations in both the 600-pound and the 1200-pound pressure classes. Steam temperatures were then generally limited to around 750 degrees, but as advances in metallurgy resulted in higher total steam temperatures the need for reheating became less, from the station economy angle as well as that of the turbine. Moreover, prevailing fuel prices did not appear to warrant the increased initial cost and the added complication of reheating. This became the general situation, with a few notable exceptions, throughout the thirties and until quite recently.

Now, however, in an effort to offset increased coal costs, which in some sections are approaching ten dollars a ton, station economy is receiving more than the usual attention. For some of the recently projected installations steam temperatures have been further stepped up to a thousand degrees or more and reheat is again coming into the picture.

Such high temperatures require much more expensive superheater materials as well as close regulation of steam temperature entering the turbine, but the extra cost appears justified in these cases by the calculated reduction in station heat rate; and adequate means for close steam temperature regulation over wide load range are available through control of furnace outlet gas temperature with final control by dampers or relatively small desuperheaters.

The best overall net station thermal efficiency, with steam, is now slightly over thirty-two per cent. This particular case involves reheat but only a moderate steam temperature. Some of the newer plants employing both reheat and very high steam temperature are expected to show thirty-four per cent or better.

Fuel Costs vs. Atomic Power

Following release of general information on atomic energy to the public, much has appeared in print concerning cheap electric power anticipated from this source. It has been indicated that atomic power plants may be producing electricity efficiently within less than ten years. This does not mean, however, that at such time it will be economical to replace present fuels with this new source of energy, but that as a result of development work now proceeding at pilot plants and research laboratories, designs may be advanced sufficiently to justify construction of a few plants in certain localities by that time. Such construction would also be contingent on sufficient supplies of uranium or plutonium at prices very much lower than today's.

The principal advantage sought through the use of atomic energy for power generation would be lower cost per kilowatt of energy delivered. The greatest saving should be realized in areas where costs of presently available fuels are highest. Such areas, of course, must have sufficient demand for electrical energy to require a plant of at least 100,000 kw which is now estimated to be the economic minimum size of an atomic power plant.

However, lowered fuel cost may not necessarily result in appreciable saving to the ultimate consumer. When it is realized that the cost of fuel is roughly one-sixth the cost of delivery a kilowatt-hour to a customer, substantial fuel saving must be realized before the consumer can benefit materially. Moreover, it is expected that capital costs for atomic power plants will be higher which means higher fixed charges that will tend to offset any reduction in fuel costs. Should the atomic fuel costs become negligible, the total cost would then parallel in many respects that of water-power generation.

External Deposits on Boiler Heating Surfaces

***A digest of a report issued by the British* Boiler Availability Committee covering an investigation of the form and composition of deposits in a large number of boilers examined. Deposits in the high-temperature zones fall into three classes—birdnesting, bonded types and phosphatic deposits. Those in the low-temperature zones are different in character. The mechanism of deposit formation was investigated and is discussed; and the behavior of sulphates, bisulphates, phosphates and chlorides was studied, particularly chemical changes taking place in the vapor phase.**

THE British Boiler Availability Committee has just issued an interim report on "External Deposits and Corrosion in Boiler Plants," which represents the results of a careful study of many boilers and the deposits found in them. Laboratory analyses of hundreds of deposit samples has enabled a broad classification to be made and has thrown light on their formation. Those found in the furnace, on the superheater, and in the boiler proper have been classified as high-temperature deposits, while those occurring on economizer surfaces and air heaters are termed low-temperature deposits.

High-Temperature Deposits

In the high-temperature regions of stoker-fired boilers three main types of relatively hard deposit have been

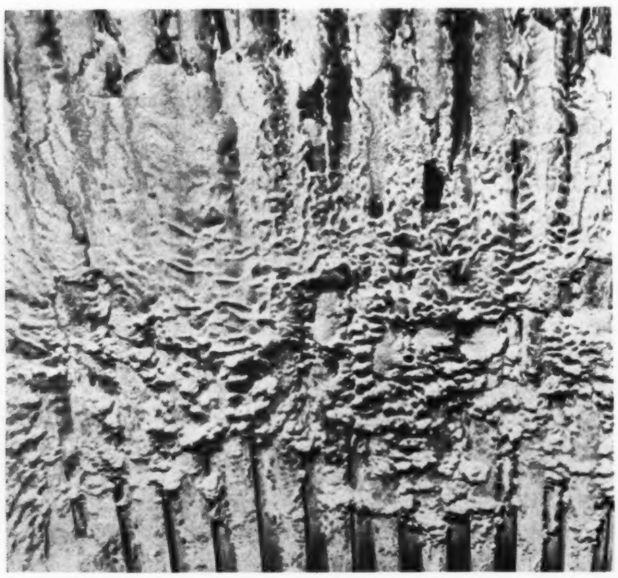

Fig. 1—Bonded deposits on first-bank boiler tubes after 732 hr (stoker fired)

identified, namely, birdnesting, bonded deposits and phosphatic deposits.

Birdnesting is generally found on the first bank of boiler tubes, although it is occasionally encountered in high-temperature superheaters. It is more prevalent in older boilers in which the first bank of tubes is set relatively low over the fire or in cases where high superheat requires high furnace outlet temperature. It is often encountered with pulverized coal.

The composition of birdnesting deposits is usually similar to coal ash; that is, it consists largely of fly-ash particles bound together as the result of sintering.

Bonded deposits are characterized by the bonding together of ash particles by some kind of cementing substance that softens at relatively low temperature. They are extremely hard and compact and occur generally on superheater tubes, although sometimes also on boiler tubes. In the opinion of the Committee they are most serious with regard to boiler availability.

Such deposits differ from those in birdnesting in that they contain from 10 to 50 per cent of material that is soluble in water, the soluble portion being composed chiefly of sulphates or bisulphates of sodium and potassium which provide the bonding. The bisulphates are more troublesome than the sulphates, partly because they melt at lower temperature and partly because they combine with certain kinds of fly ash (that formed from pyrites in the coal) to form slag-like aggregates. A num-

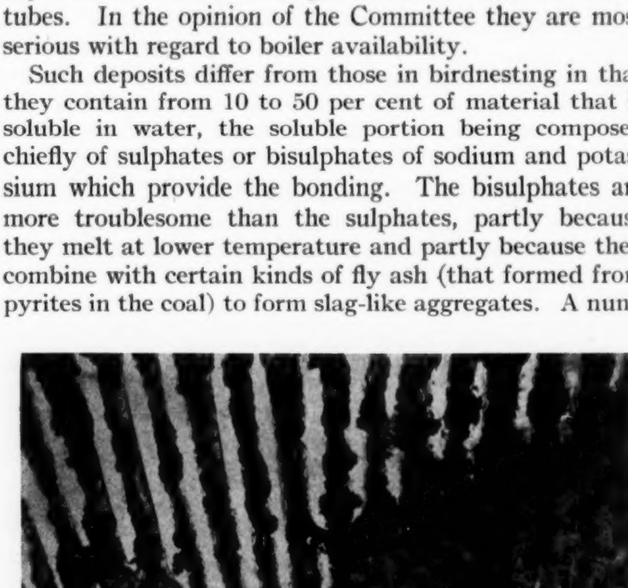

Fig. 2—Phosphatic deposit on superheater tubes after 800 hr

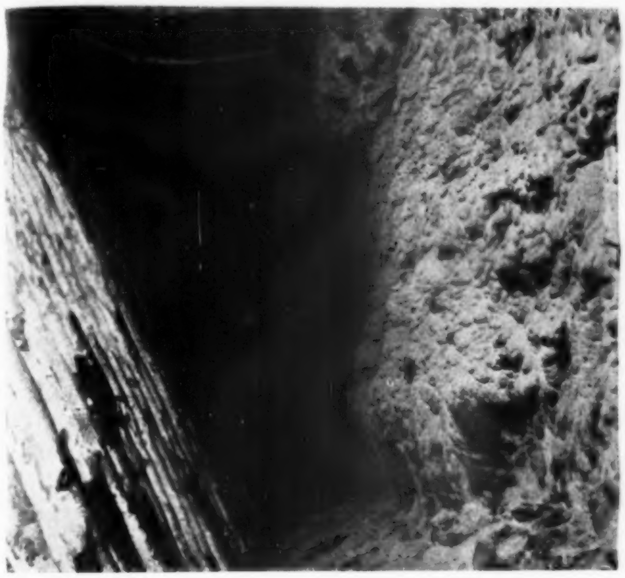

Fig. 3—Inlet to pendent superheater (right) after 718 hr

ber of tests revealed that the flue gas in the regions where bonded deposits existed was hot enough to cause sintering of the cementing material but not hot enough to soften the fly ash.

Furthermore, it was observed that the inner layers of the bonded deposits were generally lighter in color than the outer layers. This was attributed to the fact (confirmed by analysis) that the inner layers contain a larger proportion of sodium and potassium salts whereas the outer layers are almost wholly fly ash.

The phosphatic deposits are similar in appearance to the bonded deposits, but they are bound together as a result of chemical attack of the fly ash. This attack is made by phosphorus compounds volatilized from the burning fuel. Difficulties from this type of deposit were not numerous, however, since only a small proportion of British coals contain phosphorus in sufficient quantity to cause such deposits.

Low-Temperature Deposits and Corrosion

Deposits formed in the heating surfaces of economizers are generally harder and more compact the higher the feedwater temperature. They are composed of fly ash and condensed substances, together with the products of complex chemical reactions. Moreover, the nature of the coal burned appears to have greater effect on the composition of economizer deposits than it has on the fly-ash type of high-temperature deposits. This is especially true where phosphorus is concerned, its compounds often having a bonding action on low-temperature deposits even though the amount of phosphorus released from the coal may not be high enough to cause trouble in the high-temperature region.

Economizer deposits range in composition from some that are rich in sulphate but contain little phosphate to others that contain a large proportion of phosphates and less sulphate. In general, the richer the deposit in phosphate the less soluble it is and the greater will be the difficulty in its removal.

All troublesome air-heater deposits are characterized by the presence of free sulphuric acid. They tend toward a grayish color which is determined partly by the amount of unburned carbon present and partly by the size of the fly-ash particles.

While corrosion in air heaters is often the result of the temperature in the coldest section falling below the dewpoint of the gases, it may also occur at higher metal temperatures when small quantities of sulphuric acid raise the dewpoint of the gas to 300 F or more.

Deposit Formation

Deposits of the birdnesting type are produced by the sintering or fusion of fly-ash particles which have been sticky and adherent at the prevailing temperatures.

The significant point resulting from analysis of other types of deposits is that certain of their constituents are present in far greater proportions than they are to be found in the coal ash. The most striking examples of this concentrating of material are shown by phosphorus. The same trends are shown by sodium and potassium and to a lesser degree by sulphur. The various materials appear to be formed from substances volatilized from the burning fuel.

A typical example of selective deposition is the high temperature deposit bonded by a matrix of sodium and potassium sulphates. It has been found that the softening temperature of the matrix and the sintering temperature of the deposit generally lie between the actual temperature of the heating surface and the gas temperature in the vicinity. The report expresses the opinion that selective deposition caused by gas and heating surface temperatures may account not only for the production of deposits rich in sodium and potassium on boiler tubes and superheaters, but also for the presence of large proportions of other substances in other sections, such as the economizer.

A study of the volatilization of the various materials from the fuel bed showed that the sodium and potassium are easily driven off and appear to come principally from areas where the temperature of the fuel bed is high and where smoke is absent. While most of the sulphur in the coal appears in the gas as sulphur dioxide, some of the latter is oxidized to sulphur trioxide, although sulphur trioxide may also be released directly from the fuel bed

Fig. 4—Control vanes of induced-draft fan after 827 hr

by decomposition of substances such as calcium sulphate. It is believed that the sulphur trioxide not only is responsible for air heater corrosion, but also plays an important part in the formation of high-temperature deposits.

Evolution of phosphorus has been found appreciable only when there are chemically reducing conditions in the fuel bed, and when temperatures are sufficiently high.

Various chemical changes appear to take place in the vapor phase before the constituents concerned are finally deposited as sulphates, bisulphates, phosphates or sulphuric acid. The study of such changes formed an important part of the research, particularly the mechanism by which the sodium and potassium combine with the sulphur and with oxygen to form the bonding material of high-temperature deposits. The results suggest that the process involves reaction of the sodium and potassium vapors with sulphur trioxide. Subsequently the sulphates, or bisulphates, are deposited on the boiler heating surfaces where they produce the white inner layer of the material that is so characteristic of such deposits. This layer, which contains little ash and a large proportion of material soluble in water, provides a foundation for the deposition of additional solid or semi-solid particles.

Catalytic Action by Rust

Investigation has shown that sulphur trioxide can also be formed by catalytic oxidation of sulphur dioxide on the boiler surfaces, particularly on the superheater where it is at the necessary temperature. Results which have been published indicate that the rust on superheater tubes, and to a lesser extent, deposits on them, are catalytic at the temperatures encountered in modern boilers.

Another fact that seems to be well established is that there is less trouble with high-temperature deposits when there is adequate turbulence of the combustion gases in the furnace.

In the earlier phases of the research there was evidence that boilers burning coal containing much chlorine suffered severely from high-temperature deposits. It was also suspected that deposit trouble and particularly air-heater corrosion was bad when coals of high sulphur content were burned. More recent work has proved that these conclusions were justified.

The recent work on the effect of fuel has included an intensive study of conditions at thirty-six British power stations and resulted in analysis of about six hundred samples of deposits and over three hundred samples of coal. More than thirteen hundred microscopic slides of deposits were made.

In examining deposits from all thirteen electric generating stations in Britain that burn only the coals rich in phosphorus, but low in sulphur and chlorine, it was concluded that such coals can best be burned in pulverized form, and with good availability on traveling-grate stokers; but that rapid development of phosphatic deposits may be incurred if they are burned on retort stokers. This was explained by the fact that the amount of phosphorus available for the formation of deposits seems to be related to the temperature of the fuel bed and to the reducing or oxidizing conditions that exist, and combustion on retort stokers is under relatively reducing conditions. It was suggested that similar trouble might arise with traveling-grate stokers if too deep a fuel bed were carried, or if the air supply were not uniform. On the other hand, all the flue dusts examined from boilers fired with pulverized coal contained very little phosphate. Coals of medium phosphorus content (about 0.02 per cent) were not found to be associated with troublesome phosphatic deposits.

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Underground Gasification of Coal

Shortly before the war considerable interest was aroused by a report from abroad that the Russians were experimenting with underground gasification of coal, but very little factual information concerning this was available, either then or since. Now, according to Dr. R. R. Sayers, Director of the U. S. Bureau of Mines, a similar project is being carried out by the Bureau, in collaboration with the Alabama Power Company, at its Gorgas mine near Jasper, Ala.

The experimental work was begun in January of this year, and resulted from the Company's interest in the practical application of piping gas from a burning coal seam to the boilers of a nearby power plant.

Isolating a coal bed from an active part of the mine, two horizontal entries six feet in width were dug into a $2^1/_2$-ft coal seam and connected by a cross cut. Concrete piping was installed at each end of the two entries of the U-shaped structure. Several holes were core-drilled from the surface into the coal seam to take gas samples and temperature readings; and to start the combustion process, incendiary bombs were dropped into several of these holes. Using a compressor, air was blown into one entry as gas emerged from the other.

No difficulty was encountered in maintaining combustion, and mechanical difficulties were eliminated during the first sixteen days of the experiment. However, the resistance resulting from roof falls and other undetermined causes prevented an air flow sufficient to obtain the desired temperature in the burning coal and the quality sought in the gas. Therefore, a limited quantity of oxygen was introduced to enrich the air.

After the supply of oxygen was exhausted, an air blast was coursed through the tunnel and this resulted in a steady improvement in operating conditions and gas quality. A relatively high grade synthesis gas also was produced by alternately blowing air and steam into the burning mine. It is understood that the Russian system also utilizes alternate periods of air blasting and introduction of steam.

Roof falls, such as occurred, are to be anticipated, but in order to study what actually took place, strata overlying the burned area will be removed by bulldozers and shovels for analysis. The burned area will be steamed for several days and then flooded with water before extracting the stratified rock above the coal.

While further extensive study will be required to determine definitely the technical practicability of producing gas from a burning coal mine, indications are that this gas could be used successfully not only in manufacturing synthetic liquid fuels, but also for industrial use and burning under boilers. Since from 35 to 50 per cent of the coal in the ground is left after usual mining operations, its gasification underground may be the answer to recovery of this potential energy.

Carryover Problems and Identification of Carryover Types*

By P. B. PLACE

Research and Development Dept., Combustion Engineering Company

The four common types of carryover—priming, foamover, spray and leakage—are discussed with reference to their identification, their sources, and the factors affecting them. Of these four types, that due to foaming is the most common and troublesome and test methods are described for determining the presence of foam blankets.

IN THE investigation of a known carryover problem, the information desired is the cause, source and correction of the carryover rather than the absolute amount of impurity in the steam. In such work, the judgment, imagination, curiosity and persistence of the test engineer is of more value than his ability to read a meter or calculate a result accurately. Inability to see what is happening within the boiler is a handicap and it becomes the duty of the test engineer to devise test methods that will suggest and confirm his conclusions as to the cause and source of the carryover.

To the operating engineer, carryover is simply a nuisance condition to be eliminated as quickly as possible. He may have little appreciation of the various conditions that cause or affect carryover, and generally has a minimum of information of value for analysis of the trouble. Routine steam test data may be available, giving rating, boiler-water concentration, water level, and other conditions of the test period, but in many cases the only available evidence of the carryover is fouling of turbine blades or burned-out superheater tubes. When the carryover occurred, whether it was continuous or intermittent, and the type and degree of carryover, are often matters of conjecture.

Classification of Carryover

Carryover problems can be divided, roughly, into two general classes: those where the carryover is definite and often excessive when certain limits of rating, concentration, or water level are exceeded; and those where routine tests show little if any carryover but loss of superheater tubes or fouling of turbine blades indicate that a carryover condition exists.

Carryover, itself, may be classified under four types.

1. Priming, which is the development of excessive moisture in the steam due to spouting or surging of boiler water into the steam outlet.
2. Foam carryover, or foamover, which is the development of various degrees of moisture in the steam due to carryover of foam from the drum.
3. Spray, mist or fog, which are degrees of atomization of the boiler water, steam-borne from the drum by the steam in much the same manner as dust is carried by air currents.
4. Leakage, which is a general term applied to leakage or by-passing of impure steam, or boiler water, through the drum internals.

Factors Affecting Carryover

A relatively large number of factors may affect these types of carryover to different degrees, and it is by analysis of the effect of such factors on the carryover condition that the type and source of the carryover may be identified. The following tabulation gives a list of typical factors under three classifications of "Mechanical Conditions," "Water Conditions" and "Operating Conditions."

TYPICAL FACTORS AFFECTING CARRYOVER CONDITIONS

Mechanical Conditions	Water Conditions	Operating Conditions
Boiler design	Source and makeup	Rating
Drum sizes	Concentration	Changes in rating
Number of drums	Alkalinity	Pressure
Drum internals	Organic matter	Water level
Circulation	Suspended matter	Changes in level
Radiant vs convection heating surface	Chemical feed	Blowing flues
	Inherent foaminess	Blowing safety valve

In the event of a carryover being of unknown source, we may identify the type by determining the effect of these various factors in much the same manner as a doctor diagnoses an ailment by inquiring into the patient's diet, activities and environment.

It is important to note that these factors cannot be listed in order of their importance, nor are they of equal importance, as their effect varies in different cases. These factors should not be considered as causes of carryover, but as conditions that may be varied for purposes of testing a carryover condition in a single boiler, or used for purposes of comparing carryover conditions in different boilers.

Sources of Carryover

There are two distinct phases of a carryover condition. First, there is the development of a source of carryover within the boiler, and second, there is development of actual carryover. Since many of the above factors may affect both the development of carryover sources and of carryover itself, a multitude of combinations of factors may result in a variety of operating results.

It is often a minor mystery why, out of a number of similar boilers operating under more or less the same conditions, one will give carryover trouble, why some boilers have high boiler-water concentration limits and others have low limits; why superheater tubes fail after tests have shown good steam purity; or why a boiler may give good steam today at a high rating and concentration, and

* A paper presented at the Seventh Annual Water Conference, Pittsburgh, Pa., January 6–8, 1947.

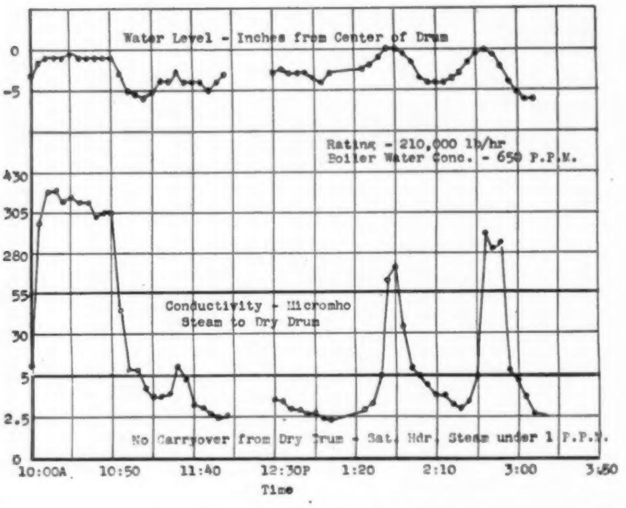


Fig. 1—Example of priming caused by high water level

give carryover tomorrow at a lower rating and concentration.

It is obvious that if high water levels, atomization of boiler water, and formation of foam films did not develop in a boiler, we would not have priming, spray carryover or foamover. On the other hand, all three of these sources may be, and usually are, present without causing actual carryover. The burden of controlling these sources of carryover falls on the drum internals, which are designed to handle reasonable amounts of spray and foam and operate with an extremely high overall efficiency. Carryover problems develop when the sources of carryover become excessive and it is the variety in the development of these sources that results in the variety of performance. Obviously, if drum internals become submerged by high water level, priming is likely to result or if similarly submerged in excessive amounts of foam, foamover is likely to occur.

Let us for a moment, make a simple analysis of the process of obtaining pure steam. The process of separation and purification is not a process of separating steam from water, but rather of separating water from steam. With a circulating ratio of say 10 lb of water per pound of steam, and with a boiler water of say 1000 ppm concentration, the contamination to be separated from the steam amounts to 10,000 ppm. To reduce this contamination to the desired 1 ppm in the outlet steam, 99.99 per cent of the circulating water must be separated in the drum. When this liquid is present in various proportions of bulk liquid, spray and foam films, it is not surprising that this high overall efficiency is not consistent in all boilers.

Test Methods

In making tests for the identification of types of carryover and their sources, arrangements should be made to obtain continuous readings on such major factors as rating, boiler-water concentration, water level and steam purity over a period in which a number of operating conditions are varied. Minor conditions, such as periods of feeding chemical to the boiler, blowing flues, popping of safety valves, etc., are recorded and the plotted data of such tests present a coordinated picture, suitable for analysis of the problem. It is important that the readings be continued during changes in operating conditions as, in many cases, these operating changes cause intermittent carryover that is not reflected in occasional or routine tests under fixed conditions. Although such a program may seem to be time-consuming, it may be completed rapidly because it is not necessary to hold any given set of operating conditions more than a half hour to obtain the desired information. The important thing to remember is that the object of such tests is to determine the conditions that precipitate or eliminate the carryover, not only so that these conditions may be avoided during regular operation, but so they may be analyzed to determine the type and source of the carryover.

Priming

Of the four types of carryover, priming may be passed over quickly as being relatively rare and readily identified. This type of carryover is usually due to too high water level, spouting of submerged riser tubes or sudden swelling of the water in the boiler on drop in pressure or sudden increase in rating. Boiler-water concentration is seldom a factor in priming, a visibly high water level or unusual surging in the gage glass identifying this source without trouble.

In Fig. 1, a typical priming condition is shown by plotted results of a test. Operating at constant rating and water concentration, the potential source of carryover is evident when the water level was increased to the center of the drum. Note that the conductivity scale changes at 5 and 55 micromho and that with water level 4 to 5 in. below the drum center, the steam to the dry drum is less than 5 micromho. The sensitivity to water level was due, in this case, to the position of the steam circulators which were low in the drum to meet installation restrictions. Lowering normal water level from 5 to 10 in. below the drum center eliminated the source of the carryover and allowed operation of the unit to over 600,000 lb per hr and 1500 ppm concentration.

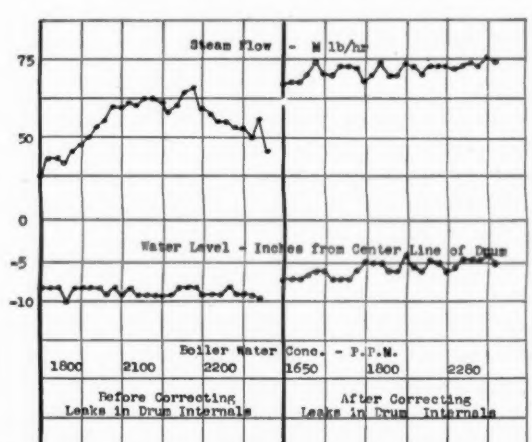


Fig. 2—Leakage carryover, before and after change in drum internals

Leakage Carryover

Leakage carryover can also be eliminated as a major type of carryover, but can be troublesome because it is often localized. Leakage is directly traceable to poor design or installation of drum internals and should be suspected in event of localized superheater failures. At times, the local contamination may not be sufficient to be reflected in purity tests of the total steam flow and the use of local sampling lines may be necessary to confirm the leakage. A careful inspection of the drum internals will usually reveal this source of carryover. In cases where the leakage is sufficient to register in purity tests of the total steam flow, it will be found that the impurity increases slowly and steadily with rating and is relatively insensitive to changes in water level and boiler-water concentration.

Fig. 2 shows data on a leakage carryover condition, before and after correction of the drum internals. Note that the carryover was not excessive, but followed the changes in rating. After correction of the leakage, the unit could be operated at higher rating and higher water level without trouble.

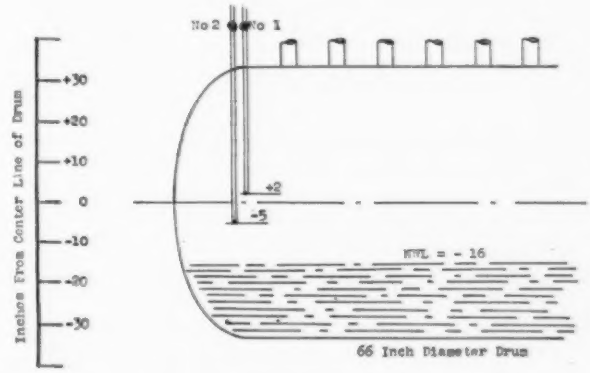
Spray Carryover

Spray carryover covers a wide range in degree of carryover, from the small amounts of atomized mist that account for the normally small impurity in commercial steam, to heavy carryover when the capacity limits of the boiler or drum internals are much exceeded. This source of carryover is present in all boilers to different degrees and is the function of the drum internals to separate and filter out such spray before the steam leaves the drum. Development of spray carryover indicates failure of the drum internals due to exceeding the velocity limitations of the purification equipment. It is characterized by initial development at less than full rating and by a consistent increase with increase in rating. If rating is increased sufficiently, this type of carryover becomes similar to priming. True spray carryover is not sensitive to changes in boiler-water concentration, but will change to foamover when foaming develops in the boiler. A familiar type of spray carryover is the half per cent moisture in steam that used to be permissible and amounted to from 5 to 50 ppm of solids impurity. Improved methods of filtering out the steam-borne mist have reduced this former standard to less than 1 ppm.

Foam Carryover

Foam carryover, or foamover as it may be termed, is by far the most common, most troublesome, and most erratic type of carryover. Foam forms in the steam generating sections of the boiler when the water films around the generated steam bubbles are stabilized by the impurities in the boiler water. The boiler circulation carries this foam up to the boiler drum where it tends to accumulate on the water level. If the rate at which the foam is delivered to the drum is less than the rate at which the foam bubbles are destroyed, there will be a limited thickness of foam blanket on the water level, but no carryover under normal conditions. If, however, the rate of foam delivery to the drum exceeds the rate at which the foam can be destroyed, the foam eventually fills the drum and is carried out by the steam.

It is important to note that the factors which are involved in development of foaming in the boiler are not necessarily the same as are involved in foam carryover, but that foam carryover cannot develop unless there is foaming in the boiler. Foaming is basically a result of chemical conditions, and boiler-water concentration and composition are the important factors involved. Any condition of carryover that can be precipitated or eliminated by a change in boiler-water concentration, other operating conditions being equal, may safely be assumed to be due to foaming. Actual rating on the boiler and actual boiler-water concentration values may have little significance for comparison with performance of other boilers in other plants. When operating just below a critical concentration limit, this type of carryover is very sensitive to minor operating conditions such as a change in rating, feeding chemicals to the boiler, blowing flues or even opening a blowdown valve.



Rating K lb/hr	Boiler Water P.P.M.	Water Level Inches	Blowoff No 1 (+2")	Blowoff No 2 (-5")	Foam Blanket on Water Level Inches
225	2700	-16	D	W	Under 18-Over 11
225	2700	-13	W	W	Over 15
225	3300	-13	W	W	Over 15
225	3940	-13	W	W	Over 15
225	5020	-13	W	W	Over 15
225	5300	-13	W	W	Over 15

No Carryover From Large 66 Inch Diameter Drum

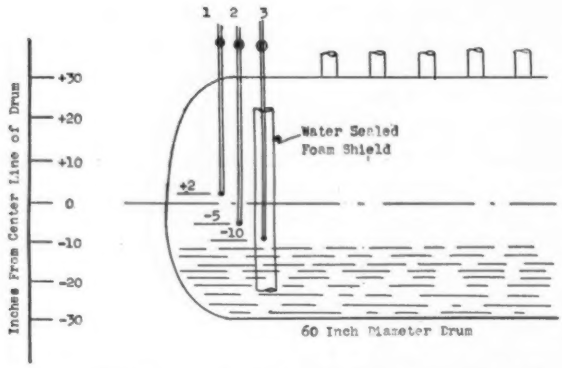
Fig. 3—Method of determining foam blanket on water level

Special Tests for Identification of Foam

Much of the special test method that has been devised for identification of carryover has been for the purpose of demonstrating the development of foaming and the presence of a foam blanket on the water level. Many of these tests have been suggested by observations on a low pressure test boiler, fitted with windows and electric lights. It has been found that the general mechanism of foam accumulation in the drum and of foam carryover is practically the same in both low- and high-pressure boilers.

Foam Accumulation on Water Level in Drum

The presence of a foam blanket on the water level may be demonstrated by simple test lines as shown in Fig. 3. Small diameter lines are installed in the drum at fixed elevations above the water level and fitted with valves to allow free blowoff to atmosphere. In the absence of foam on the water level, these test lines will give a hot, dry and nearly invisible blowoff of superheated steam, but as they become submerged in foam, the discharge changes to a cold, visible and very wet blowoff. In Fig. 3, two such lines are located 11 and 18 in. above normal gage-



Rating M lb/hr	Boiler Water P.P.M.	Water Level Inches	Blowoff No 1 (+2")	Blowoff No 2 (-5")	Blowoff No 3 (-10")	Foam Blanket on Water Level Inches
175	2950	-16	D	D	-	Under 11
175	2950	-13	D	W	-	Under 15-Over 8
185	3000	-16	-	-	D	Under 6
185	3000	-13	-	-	D	Under 3
185	3000	-12	-	-	D	Under 2
200	2950	-16	D	W	-	Under 18-Over 11
200	2950	-13	W	W	-	Over 15
225	2950	-16	D	W	-	Under 18-Over 11
225	2950	-13	W	W	-	Over 15

Foam Carryover at 225,000 lb/hr
With 3400 P.P.M. at -12 " Level

Fig. 4—Method of shielding water level test lines

glass water level. As seen by the tabulated observations, the foam blanket on the water level is over 15 in. thick, but no carryover developed with high concentrations because of the liberal diameter of the drum.

In Fig. 4 a similar test line installation in a 60-in. diameter drum shows a foam blanket of 12 to 15 in. Note that foam carryover developed with relatively small increase in concentration and water level.

When first used, these test line discharges suggested that the water level in the drum was higher than in the gage glass, or that the observations were false because of splashing and surging in the drum. In order to confirm the results, a method of shielding the blowoff line by a water-sealed tube was developed, as shown in Fig. 4. Shielded lines will not register foam levels unless the foam builds up and flows over the top of the shielding tube. As noted in the data, this shielded test line discharged dry steam within two inches of the gage-glass water level.

Such test lines have been used many times, both in the active section of the drum and at the ends of the drum where they are not subjected to excessive splash or surging. They may be used to determine operating water levels when boiler water concentrations are low, but will register foam levels when there is a blanket of foam on the water level, unless shielded as described above.

Fig. 5 shows data taken with a single test line located in the front drum of a three-drum boiler. Note that this test line shows dry steam, 6 in. above the center of the drum, at all ratings with boiler water concentration below 1200 ppm; but shows the presence of foam even at low ratings when the concentration is above 1800 ppm. Carryover from this boiler was traced directly to excessive amounts of foam carried over from the front drum to the rear drum, where it flooded the steam washer and steam dryer and prevented proper functioning of this purification equipment.

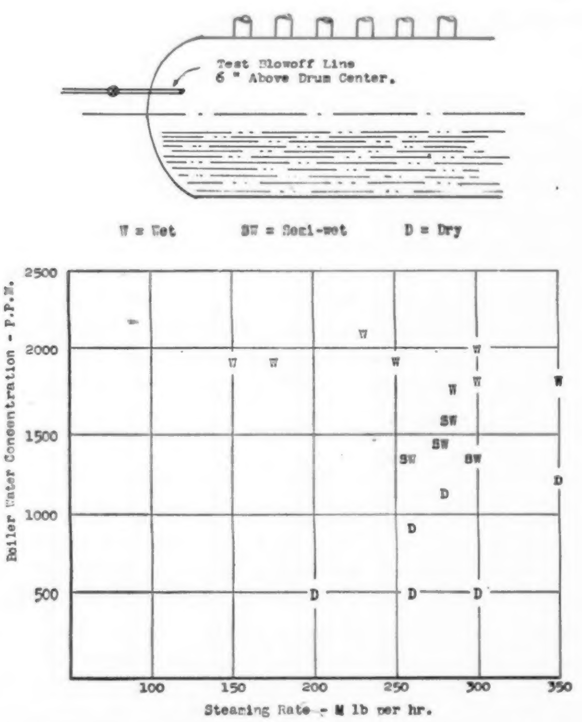


Fig. 5—Results of foam blanket test in front drum of three-drum boiler

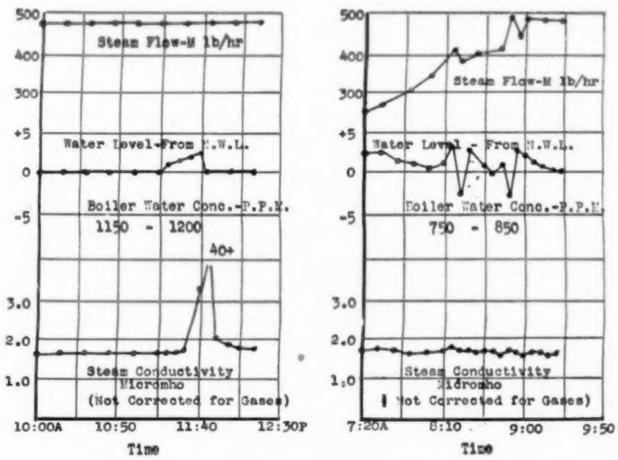


Fig. 6—Foam carryover test showing sensitivity to change in water level

Development of Foaming with Increased Concentration

In the usual method of testing a boiler for carryover, the steam is sampled at the boiler drum outlet or superheater inlet. If carryover occurs, the drum internals are usually blamed without consideration of the conditions under which they may be operating. Further, if the unit happens to be sensitive to carryover within the normal range of rating, water concentration or water level, there may be one or more periods of heavy carryover to the superheater and turbine during the tests, and in the haste to correct the condition, much valuable information may be lost.

Figs. 6 and 7 show data of tests by this method, the carryover in each case being kept low by careful operation and slow changes in operating conditions. In Fig. 6 operating at constant load of 480,000 lb per hr and constant water concentration of about 1200 ppm, small

carryover was precipitated by an increase in water level. Such carryover might be assumed to be due to the change in water level alone, but repeating the test at lower concentration showed no carryover developed with higher and fluctuating water level and during a load pickup. The basic source of the carryover was foam formation at the higher concentrations. The small increase in water level also raised the foam level in the drum and resulted in carryover. The unit was not inherently sensitive to changes in water level alone.

In Figure 7, a concentration limit test was made by operating at constant load and allowing concentration to build up slowly until carryover developed. When steam samples showed evidence of potential carryover at 2500 ppm, the boiler was blown down to safe operating limits. Incidently, this test was made at reduced load and when repeated at full load, the concentrated limit was found to be about 1800 ppm. Concentration limits, determined in this manner, under carefully controlled conditions, are critical limits and sensitive to minor changes in operation

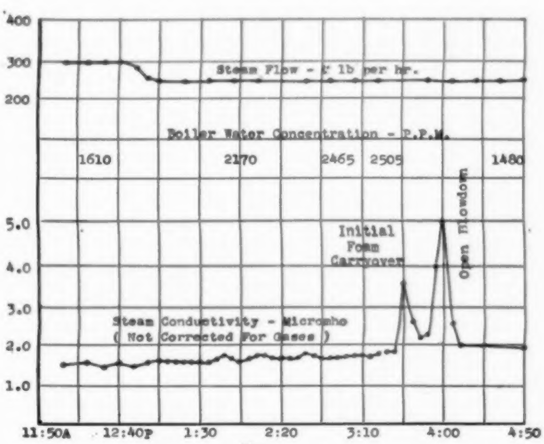


Fig. 7—Results of concentration limit test

of the boiler. Safe limits for regular operation usually have to be carried 200 to 500 ppm lower.

An improvement in this method of testing is illustrated in Figs. 8 and 9. As shown in the drum diagrams, steam sampling lines are located in the drum between the various stages of separation and purification. Such samples are much more sensitive to potential sources of carryover and will register before actual carryover occurs. By keeping a close watch on these samples, carryover can be predicted and the test stopped before undesirable impurities are carried over into the superheater or turbine.

In Fig. 8 the development of foaming at low rating and low boiler water concentration is clearly shown. At rating of 365,000 lb per hr and concentration of 395 ppm, dryer inlet steam tested 40 to 50 micromho which is typical of a spray condition. With increase in concentration to 485 ppm, the increase in conductivity of the steam sample was greater than expected and indicative of initial foam development. Evidence of foaming was further indicated by sensitivity to a small swing in rating. With rating reduced to 230,000 lb per hr the addition of further chemicals resulted in a radical change in conductivity of the steam sample, accompanied by a small amount of carryover to the saturated header.

In Fig. 9 the effect of foaming on performance of drum

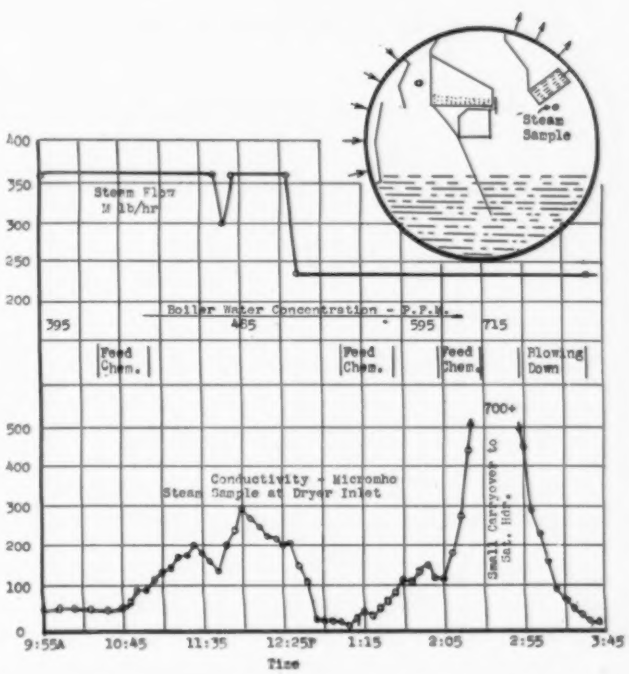


Fig. 8—Development of foaming at low rating and low concentration shown by drum steam samples

internals is strikingly shown. In this case, steam samples were taken back in the drum at the inlet of a bank of screens (No. 1) as well as at the inlet to the final dryer (No. 2). At low concentrations and in the absence of foaming, the dryer inlet sample (No. 2) registered as good steam purity as at the superheater inlet, and the screen inlet sample (No. 1) showed only about 50 micromho of spray impurity. With increase in concentration to only 385 ppm, the screen inlet sample (No. 1) showed radical increase in conductivity, suggestive of foam development. Protected by the screen bank, the dryer inlet

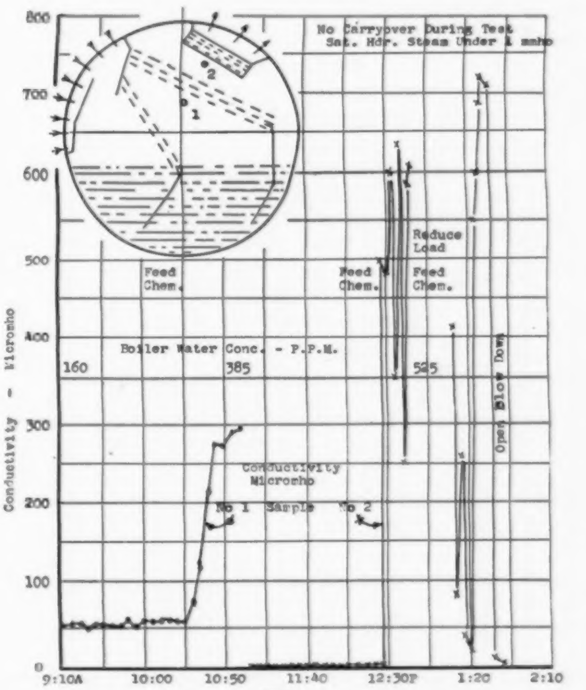


Fig. 9—Improved method of testing shows excessive foam development without carryover to header

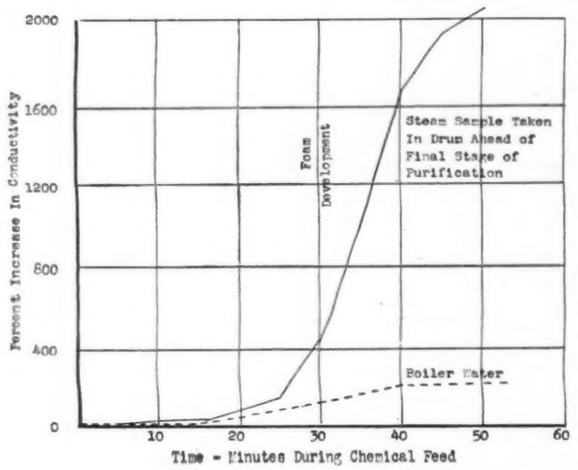


Fig. 10—Relative rates of increase in conductivity of drum steam and boiler water samples during addition of chemicals

steam (No. 2) continued to show less than 5 micromho conductivity until concentration was increased to 525 ppm. This increase from 385 to 525 ppm increased dryer inlet steam conductivity from less than 5 to over 600 micromho, a positive indication of excessive foam accumulation in the drum. The screen inlet sample under these conditions tested over 800 micromhos and was practically constant. It was evident that this sample line was completely submerged in the foam blanket in the drum.

Note that despite these radical changes in quality of the drum samples, no carryover developed and the test was completed under full control. The limitations of the unit, and the effect of various operating factors, could be determined without danger of serious carryover to the superheater and turbine. These results show clearly the burden imposed on drum internals when excessive foaming develops entirely as a result of increase in boiler-water concentration. Normal full load on this unit is 370,000 lb per hr, but peak loads of over 420,000 lb per hr have been carried with outlet steam conductivity of less than half a micromho, as long as boiler water concentration was below the foaming limit.

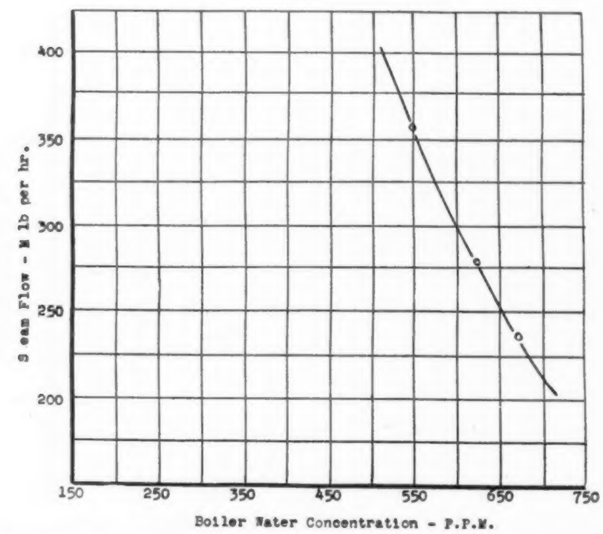


Fig. 11—Test results showing concentration limits at which excessive foaming develops

Fig. 10 shows the relative increase in conductivity of boiler water and drum steam sample during the addition of chemicals. During the initial stage of chemical feed, before excessive foaming developed, the two conductivity records parallel each other as would be expected if the moisture in the steam is boiler water spray. With development of foaming, the conductivity of the steam sample increases radically, showing over 2000 per cent increase.

Fig. 11 shows the plotted break points in drum steam conductivity for various ratings and boiler water concentrations. Note that the concentration is of much more significance than the rating. These values do not represent concentrations at which carryover occurs, but at which excessive foaming develops. Drum internals will control this foaming to a limited extent, but above these concentrations carryover is likely to be precipitated by minor operating changes such as a change in rating or in water level. In this particular unit, however, excessive foaming at relatively low boiler-water concentration is the basic cause of carryover.

It should not be inferred that foaming develops at any particular boiler-water concentration. In rare cases, it may develop at very low concentrations or conversely, it may not develop at relatively high concentrations. If a boiler has carryover the methods here described may be of help in tracing the basic cause of the trouble.

Summary

The four common types of carryover are (1) priming, (2) foamover, (3) spray and (4) leakage. In investigation of carryover problems it is desirable to identify the type of carryover involved preliminary to correction.

Both the development of sources of carryover, and of carryover itself, are affected to different degrees by a variety of factors which may be classified as mechanical conditions, water conditions and operating conditions. A number of combinations of these factors may produce a variety of performance, as evidenced by the different limits in rating, concentration and water level that exist.

Of the four types of carryover, that due to foaming in the boiler is the most common, the most troublesome and the most erratic. Special test methods are devised for demonstrating the presence of foam blankets on water levels in drums and the development of foaming with increase in boiler water concentration, and for obtaining boiler performance data without danger of serious carryover to the superheater and turbine.

Modified Super-Regenerative Arrangement Proposed

In a paper reviewed in COMBUSTION of September 1944, J. F. Field, Electrical Engineer, City of Edinburgh, Scotland, proposed a steam "super-regenerator" employing a nearly reversible cycle with multiple regeneration up to the maximum operating temperature. Recently Mr. Field has been granted a patent on a modification and claimed simplification of this scheme, presented as two alternatives, each employing a compound cycle. In the first the fluids of the primary and the secondary cycles are separated, and in the second they are combined. In view of the previous publication of the first proposal, this later scheme is reviewed for those interested in such studies.

THE thermal efficiency of a steam cycle depends primarily upon the absolute temperature at which heat is added to and rejected by the cycle. Since heat is usually rejected at the lowest practicable temperature, heat must be added at a higher temperature to improve the efficiency of a cycle. In the Rankine steam cycle, the weighted average temperature of heat intake is relatively low even with regenerative feedwater heating and comparatively high superheat. Most of the heat is added in the boiler at the saturation temperature corresponding to the operating pressure. There would be a substantial thermodynamic advantage in taking all the heat into the working fluid at the upper limit of temperature imposed by the strength of the constructional materials available.

By using a working fluid such as mercury, which has a critical temperature much in excess of that of water, it is possible to increase the intake temperature. The mercury cycle can be superimposed on a conventional Rankine steam cycle, resulting in a binary cycle having a high thermal efficiency. Mercury as a working fluid however, has many disadvantages. It is scarce and expensive. Its vapor is poisonous and has a deleterious effect on metals which come in contact with it. It would be preferable to use a working fluid that does not have these disadvantages, yet can take heat into the cycle at a high temperature.

On this premise the inventor of the "super-regenerator" steam cycle, Mr. J. F. Field, has conceived two compound cycles. Each of the compound cycles is arranged so that all of the heat is taken into the primary cycle. By using superheated steam as the working medium in the primary cycle, it is possible to attain a high initial intake temperature. In the ideal or Carnot cycle, heat is added by a reversible isothermal process. In these two proposed cycles an isothermal intake process is approximated by alternately expanding and reheating the steam. Since the originator considers these compound cycles modifications of the "super-regenerator" cycle, previously described, they will be designated in the description that follows as Alternate 1 and Alternate 2.

Alternate 1

Alternate 1 is a compound cycle consisting essentially of a high-temperature primary cycle and, isolated from it, a lower temperature Rankine regenerative secondary cycle. The primary cycle is made up of a separately fired multi-stage superheater, a steam turbine, a multi-stage steam compressor and two steam heat-exchangers which furnish sensible and latent heat required by the secondary cycle. The secondary cycle is a Rankine regenerative cycle with steam heat-exchangers replacing the conventional boiler and superheater.

A temperature-entropy diagram for this proposed cycle is shown in Fig. 1. In the primary cycle slightly superheated steam, represented by the point V, is compressed isentropically to point Q. The steam is then alternately superheated and expanded from point Q to point R. From point R it expands isentropically to point T. The steam then alternately rejects heat to the secondary cycle and is compressed until it is returned to point V. This cycle is in effect a closed gas-turbine cycle utilizing reheat between turbine stages and intercooling between compressor stages, and working with steam as the primary fluid. A portion of the steam is bled from the turbine at point S and furnishes heat to superheat the steam of the secondary cycle. After giving up some

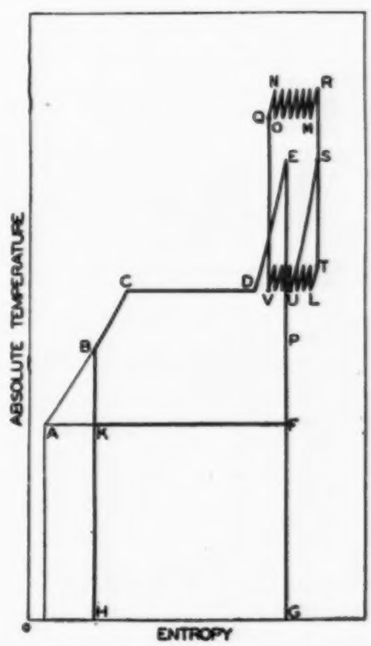


Fig. 1—Temperature-entropy diagram for first alternate

of its heat, the bled steam is returned to the cycle at point *U*.

The Rankine secondary cycle, modified by regenerative feedwater heating, is represented in Fig. 1 as *KBCDEF*. Process *KB* approximates the conditions existing with multiple regenerative heating when the relative quantities of water and bled heating steam are taken into account. Sensible heat is added to the water until it reaches the saturation temperature shown as point *C*. Steam is generated from point *C* to point *D*. The heat rejected by the primary cycle, in compressing the steam from point *T* to point *V*, is sufficient to supply all the sensible and latent heat required between the points *B* and *D*. Since heat is required from the primary cycle to superheat the secondary steam from point *D* to point *E*, a portion of the steam is bled from the expansion process at point *S*. This steam is cooled at substantially constant pressure, the rejected heat being transferred to superheat the steam of the secondary cycle.

It is possible to bleed steam from the primary cycle because the total quantity of steam circulated is substantially greater than that flowing in the secondary cycle. As previously described, the bled steam after reaching the condition represented by point *U*, combines with the steam following the process *TV*.

From the condition *E* the majority of the secondary steam is expanded isentropically to point *F*, small quantities of steam being bled at appropriate turbine stages to heat the feedwater. In the process *FK*, heat is rejected in the condenser.

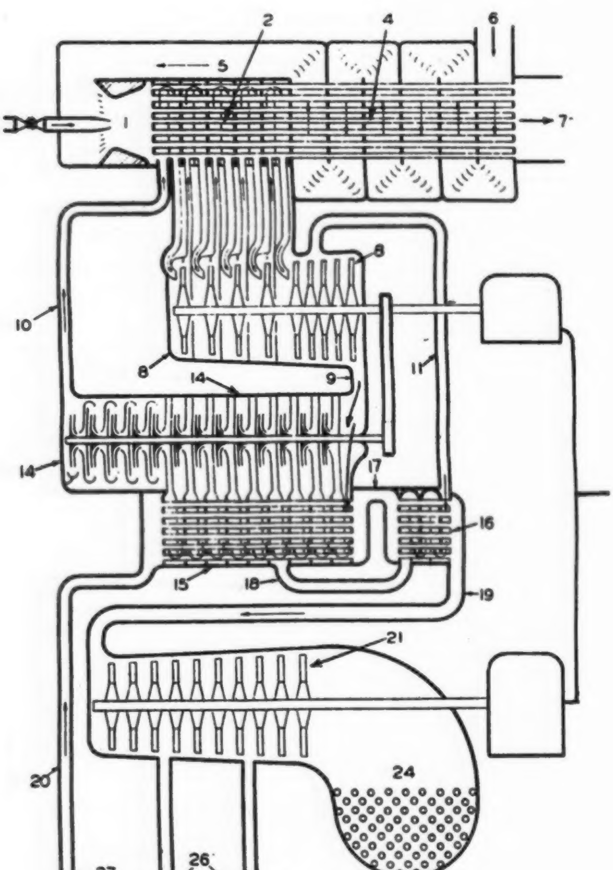


Fig. 2—Diagrammatic arrangement of equipment for cycle shown in Fig. 1

A diagrammatic arrangement of the equipment of the cycle is shown in Fig. 2. Combustion air enters at *6* and is heated in the air preheater, designated as *4*. After passing through the duct, *5*, it combines with the fuel in the combustion chamber, *1*. The products of combustion first pass over the heating surface of the multi-stage superheater, 2, and then over the air preheater surface. After compression the steam of the primary cycle enters the first stage of the separately fired superheater through line *10*. The constant-pressure heating process accomplished in the first stage of the superheater is represented by *QN* on the temperature-entropy diagram, Fig. 1. Subsequent reheating processes that occur in the multi-stage superheater are indicated by the lines parallel to *QN*, the last reheat stage being represented by *MR*.

After initial heating in the first superheater stage the steam is expanded in the first stage of the turbine, identified as *8* in Fig. 2. This expansion is represented by *NO* on the temperature-entropy diagram. After alternate heating and expansion processes the steam is expanded in the remaining turbine stages and is exhausted through line *9*. This is indicated as *RT* in Fig. 1.

After leaving the primary steam turbine, *8*, the steam passes to the first stage of the heat-exchanger, *15*, where it rejects some heat to the secondary cycle steam. This process is represented as *TL* in Fig. 1. The primary steam is then alternately compressed and cooled and leaves the last cooling stage at point *V* in Fig. 1. It is then compressed in the remaining stages to point *Q*.

The relatively low-pressure steam that is bled from the primary turbine at condition *S* (Fig. 1) passes through line *11* (Fig. 2) to the heat exchanger, identified as *16*. Here it transfers heat to the higher pressure steam of the secondary cycle. After leaving this heat exchanger, which replaces the conventional superheater in the secondary Rankine cycle, this bled steam passes through line *18* and re-enters the primary cycle in heat-exchanger *15*, essentially at condition *U* on the temperature-entropy diagram.

In the secondary cycle the hotwell pump, *25*, feeds the condensate to the feedwater heaters, *26*. At a suitable number of extraction points, between *P* and *F* on the temperature-entropy diagram, steam is bled from the turbine. This bled steam that has done some work in the expansion process then adds the remainder of its energy to the feedwater. In Fig. 2, the feed pump, or pumps, are shown diagrammatically as *27*. By taking into account the relative quantities of water and bled steam these regenerative heating processes may be indicated on the temperature-entropy diagram as *KB*.

After passing through the feed pipe, *20*, the water enters the secondary side of the heat-exchanger, *15*, where heat is added. The sensible heat added in the heat-exchanger is represented by *BC* on the temperature-entropy diagram and the latent heat added by *CD*. It will be noted that the usual economizer and boiler are replaced by this heat-exchanger, which performs the same functions, but uses the superheated steam of the primary cycle as the heating medium.

The saturated steam leaves this exchanger through pipe *17* and enters heat exchanger *16*, where heat is added corresponding to *DE* in Fig. 1. This superheated

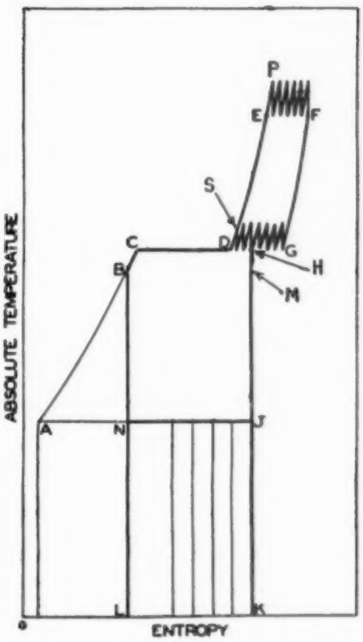


Fig. 3—Temperature-entropy diagram for second alternate

secondary steam then passes through line *19* to the steam turbine, *21*, where it is expanded. This expansion process is represented as EF on the temperature-entropy diagram.

The steam is condensed in the condenser, *24*, to complete the secondary process. This isothermal process is shown by FK on Fig. 1.

The output of the cycle is equal to the combined outputs to the primary turbine, *8*, and the secondary turbine, *21*, less that required to drive the compressor, *14*.

Alternate 2

The second alternative to the original "super-regenerator" steam cycle is similar in many respects to Alternate 1. The essential difference is that the working fluids of the primary and secondary cycles are isolated from each other in Alternate 1; whereas, they are combined in many of the processes of Alternate 2. Because of the arrangement of the first alternate it would be possible to use different working mediums in each cycle. In Alternate 2, however, a single working medium must be used.

As in Alternate 1 the primary cycle is made up of a separately fired multi-stage superheater, a multi-stage steam turbine, a multi-stage steam compressor and two heat-exchangers. One of the heat-exchangers furnishes sensible and latent heat required by the secondary cycle. In the other heat-exchanger the steam of the primary cycle rejects heat at relatively low pressure to superheat higher pressure steam of the same cycle.

A temperature-entropy diagram for this compound cycle is shown in Fig. 3. In the secondary cycle, NB approximates the conditions existing with multiple regenerative heating when the relative quantities of water and bled steam are taken into account. Sensible heat is added to the water until it reaches the saturation temperature shown as point C. Steam is generated from point C to point D. The heat rejected by the primary cycle, in compressing the steam from point G to point D is sufficient to supply all the sensible and latent heat required for the secondary cycle between points B and D.

At point D the steam of the primary and secondary cycles is combined. Superheat is added between points D and E at approximately constant pressure from the heat available by a similar constant pressure cooling process between the points F and G. The steam is then alternately heated and expanded from points E to F. Following the last expansion the steam rejects heat between points F and G, as previously described.

Alternate compression and cooling processes occur between points G and H in successive stages of a compressor and heat-exchanger. At a selected intermediate point, the secondary steam is bled off and expands isentropically along the line HJ. Heat is then rejected to the condenser by the isothermal process represented by JN.

A relatively small portion of the steam is bled at point H, the remainder of the steam continues to be compressed and cooled until it recombines with the secondary steam at point D.

A diagrammatic arrangement of the equipment components is shown in Fig. 4. Combustion air enters at *6*, is heated in the air preheater, *4*, and then passes through the duct, *5*, to the furnace, *1*. The combustion products

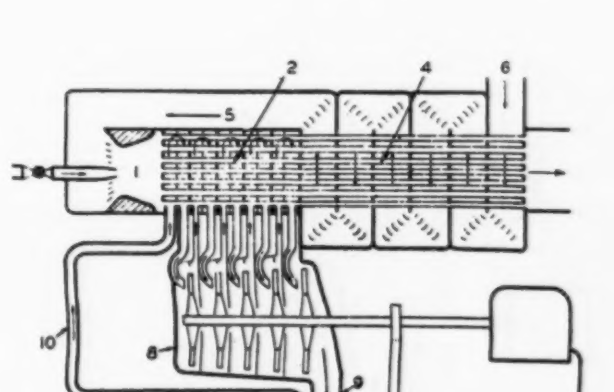


Fig. 4—Diagrammatic arrangement of equipment for cycle shown in Fig. 3

give up heat to the multi-stage superheater, *2*, and then to the air-preheater.

After initial heating, the steam enters the first stage of the superheater through steam line *10*. The constant pressure heating process accomplished in the first superheater stage is represented by *EP* in Fig. 3. The steam is then expanded in the first stage of the primary turbine, identified as *8*. Alternate reheating and expansion processes follow until the steam is exhausted from the turbine through line *9*. The condition of steam in line *9* is represented by point *F* on the temperature-entropy diagram. Heat is then given up by this relatively low pressure steam and added to the higher pressure steam in heat exchanger, *11*. These respective processes are identified as *FG* and *DE* in Fig. 3.

After leaving the heat-exchanger the steam enters the first stage of the compressor, *14*, through line *12*. The steam then rejects heat in the first stage of the intercooler which is identified as heat-exchanger *15*. Subsequent compression and cooling processes occur until the steam leaves the last cooling stage through pipe *13*. The last cooling stage is represented in Fig. 3 by *SD*. A portion of the steam is bled to the secondary process through line *18*. After expansion in the turbine, *19*, the steam is condensed in the condenser, *20*. As in Alternate 1, multiple regenerative feedwater heating is employed. By bleeding steam from the expansion process at appropriate points between *M* and *J* in Fig. 3, the feedwater temperature is raised to the condition represented by point *B* on the temperature-entropy diagram. The feedwater then passes to the secondary side of heat-exchanger *15* through feed line *24*.

In the heat-exchanger, *15*, sensible and latent heat are added to the secondary steam, represented by processes *BC* and *CD* on the temperature-entropy diagram. The saturated steam leaves through line *16* and is mixed with the steam from line *13*. The combined steam quantity enters heat exchanger *11* where heat is added corresponding to process *DE* in Fig. 3.

Since all the heat is added to this cycle in the separately fired superheater, *2*, the quantity of steam flowing through the turbine, *8*, and the compressor, *14*, with respect to the quantity bled through steam line, *18*, and returned through feed line, *24*, must be determined from the particular operating pressures and the temperatures chosen.

The actual thermal efficiencies of these compound cycles will depend, of course, upon the operating pressure and the temperature conditions selected, and upon the degree to which the equipment components can be made to approach the ideal processes described in this analysis. However, since heat may be taken into the primary cycle of each of these proposed cycles, at a relatively high temperature by processes approximating an isothermal process, and since heat is rejected by the secondary cycle at the lowest practicable temperature, high thermal efficiencies may be expected of each compound cycle.

Internal Corrosion of Furnace Tubes of High-Pressure Boilers

By RICHARD C. COREY*

A discussion of the experiences with internal tube corrosion at Springdale and Firestone, as related in two papers at the last A.S.M.E. Annual Meeting, which were reviewed in the report of that meeting in COMBUSTION of December 1946.

DURING the second session on boiler feedwater studies at the 1946 Annual Meeting of the A.S.-M.E., Messrs. Hankison and Baker described an unusual type of internal corrosion of furnace wall-tubes of high-pressure No. 2 unit at the Springdale Station,[1] and Professor F. G. Straub described a very similar condition in a high-pressure boiler of the Akron, Ohio, plant of the Firestone Tire and Rubber Co.[2] In both cases the tube metal ruptured in a brittle manner, and the microstructure showed marked intercrystalline attack. Deep internal pits in the fire side of the tubes, which were filled with dense plugs of Fe_3O_4 also characterized tube damage of both units. A summary of the known characteristics of this type of corrosion, and the corrective measures applied, is given in the following discussion.

These two papers were the first to present detailed, informative case histories of a type of internal corrosion of high-pressure steam generators, which, although not considered to be prevalent, has caused concern where it has occurred. This may be appreciated from the appearance of the furnace wall-tube shown in Fig. 1, which is typical. Information presented by these authors on the operating conditions prior to tube damage, the appearance of the corroded tubes, the nature of the corrosion products, and the steps taken to prevent further attack, afford an invaluable basis for determining the cause, effect, and prevention of tube failures. Certain factors about the Springdale and the Firestone units are contradictory so it is evident that the last word has not been said regarding the mechanism and the prevention of internal corrosion of the type considered by these papers.

It appears that the cause of internal corrosion of furnace wall-tubes falls into three distinct catagories:

1. Where fluid circulation in the wall circuits is inadequate.
2. Where proper conditioning of the water is not maintained.
3. Where tests show that neither circulation nor water conditions are considered to be inadequate.

It is with the last that we are primarily concerned, since the first two are amenable to correction. In the writer's experience with wall-tube failures, the main characteristics of those jobs where internal corrosion occurs despite adequate fluid circulation and water treatment has been as follows:

(*a*) Periods of operation from five to ten years with infrequent or no wall-tube failures, and then, with no radical changes in operation or water treatment, sudden, frequent failures occurred as the result of nonductile cracks and ruptures of wall tubes. The writer is familiar with at least four cases in this class, one of which operated without trouble for eight years, and another for ten years, before a large number of failures began to occur. Yet, measurements of the fluid velocity and tube metal temperatures in the furnace wall tubes, and careful study of the records of the boiler water concentrations over a period of several years, showed these factors to be within the limits that experience has shown to be satisfactory.

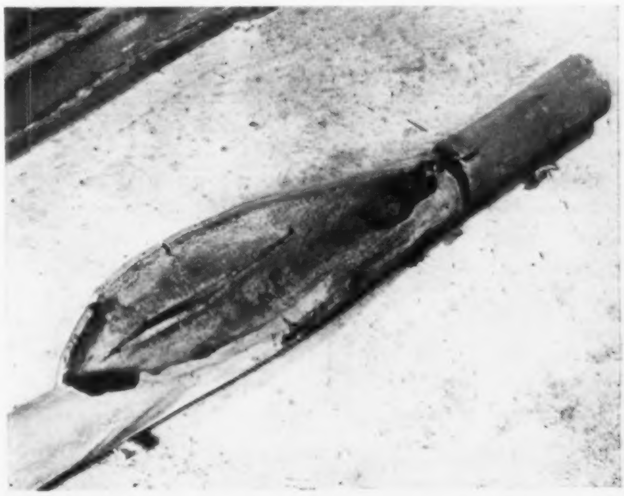


Fig. 1—South wall tube at Firestone in which rupture took place 3 to 4 ft above the floor of the furnace

(*b*) In several cases the failures occurred at isolated points in the water walls, with absolutely no evidence of damage in adjacent tubes or apparent relation of the failure to its height above the floor or proximity to burners.

(*c*) In all cases, the fire side (internal) has been deeply pitted, the pits being filled with brittle, dense plugs of Fe_3O_4—frequently showing the laminations described by Messrs. Hankison and Baker. In the Firestone unit, large pieces of this scale were found in the bottom headers during outages, apparently having become detached from the pits by temperature changes or alternating mechanical stresses incident to operation. It is significant that the first occurrence of these pieces preceded

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[1] "Corrosion and Embrittlement of Boiler Metal at 1350-Psi Operating Pressure," by L. E. Hankison and M. D. Baker.

[2] "Wall-Tube Corrosion in Steam Generating Equipment Operating Around 1300 Psi," by F. G. Straub.

the more serious failures by a few years, suggesting that corrosion probably had been progressing slowly for some time, and the sustained loads on the boiler, incurred by wartime activities, accelerated the attack to a point where numerous failures occurred within a short period of time.

The operating histories of the Springdale and the Firestone boilers are strikingly similar in some respects, as may be seen in Table 1.

The two significant differences between the factors given in Table 1 are the lower pH of the boiler water of the Firestone unit, and the fact that acid-cleaning preceded the failures at Springdale, while there have been no failures, or evidence of incipient attack of wall tubes in the Firestone unit since it was acid-cleaned.

TABLE 1—COMPARISON OF SOME OPERATING AND CORROSION CHARACTERISTICS

		Springdale	Firestone
1.	Boiler pressure, psig	1350	1400
2.	Boiler rating, M lb per hr	470	300
3.	Slag tap, type	Continuous	Intermittent
4.	Feedwater makeup, type	Evaporated	Evaporated
5.	Unit first placed in operation, yr	1938	1935
6.	Operating period before tube damage became serious, yr	7	10
7.	Water conditions prior to failures:		
	a. History of dissolved oxygen in feedwater	Yes	Yes
	b. Oxygen scavenger	None	Akon, sulfite
	c. pH of boiler water	11.1	Yr. Avg. Min. Max. 1941 10.5 9.0 10.8 1942 10.5 9.0 10.8 1943 10.3 9.0 10.5 1944 9.7 8.1 10.9
	d. Phosphate salts used: Na	1938–1942	1935–1944
	K	1942–1946	1944–1945
8.	Location of attack	Chiefly fire side of furnace wall tubes, but also in generating, screen, and roof tubes.	Fire side of furnace wall tubes at elevations 2 to 17 ft above the floor.
9.	Type of damage	Bulges and nonductile cracks. Internal surfaces pitted.	Same as Springdale
10.	Type of corrosion product in pits and cracked or ruptured areas	Black, dense, brittle, laminated plugs of Fe_3O_4. Usually contain appreciable copper. Loose plugs frequently found in headers.	Same as Springdale
11.	Acid-cleaning of boiler	Done before failures occurred.	Not done until failures occurred.
12.	After outage and draining, boiler was refilled with	....	Untreated, partly deaerated condensate.
13.	Period of operation without further tube damage, since corrective steps were taken	18 months	20 months

In Table 2 the corrective measures mentioned by the authors are recapitulated for the purpose of easy comparison.

TABLE 2—CORRECTIVE MEASURES TO PREVENT ATTACK

Springdale	Firestone
Reduced dissolved oxygen in feedwater to 0.02 ppm or less	Reduced dissolved oxygen in feedwater to less than 0.02 ppm
Sulfite maintained at 3–10 ppm excess in boiler water	Maintained boiler water pH between 10.5 and 11.0
Reduced ammonia content of feedwater	Refilled boiler after each drainage with deaerated condensate adjusted to pH = 10.5, with NaOH
	Maintained PO_4 under 10 ppm, with B-reading less than 3.0 ml. N/30 HCl

Although the history of the Firestone unit appeared to preclude water-wall circulation as a factor, since it had operated for several years without appreciable trouble with wall tubes, it was decided to determine the fluid velocities in selected wall tubes and to install thermocouples on the furnace side of the same tubes, at two elevations, in order to measure the metal temperatures and determine if they were excessive under normal operating conditions. Accordingly, double-impact pitot tubes, described elsewhere,[3] were installed in the lower end of tubes Nos. 26 and 44 in the south side wall, and 42 and 68 in the front wall. The differentials were measured with Merriam high-pressure manometers, using Vizzene "A" as the indicating fluid. All measurements were corrected for density differences in the pressure legs connecting the manometers to the pitot tubes. Chromel-alumel couples, installed as described by Humphreys,[4] were placed on the same tubes at elevations of 3 ft and 13 ft above the slag floor.

With the exception of short periods when test personnel were temporarily assigned to other duties, velocity and temperature readings were taken twice daily with a portable potentiometer for a period of about seven months. A recording potentiometer connected to six of the couples provided a continuous record of tube temperatures and showed the effect of operating variables. Fig. 2 is a plot of temperature and velocity data obtained during June 1945 and Fig. 3 is a record of the water analyses for a period of two months. These data are typical of the entire time that records were obtained.

It will be noted that none of the temperatures was excessive, the maximum being 100 deg F above the saturation temperature, and the average being about 40 deg F. Also, the metal temperatures at 3 and 13 ft above the floor were not appreciably different.

The fluid velocities, also given in Fig. 2, were considered to be adequate for a unit of its type, and over a period of two months the average velocities were approximately as follows:

Tube No.	Velocity, fps
42W	1.1
68W	1.2
26S	1.4
44S	1.1

Since March 1945, at which time the unit was acid-washed and placed in operation upon Straub's recommendations, four inspections of the furnace wall tubes have been made. This was done by removing the handhole plates from the upper and lower headers, lowering a light in each tube through the upper header, and sighting upward into the tubes through the lower ends with a focusing telescope. Long experience with this method made it possible immediately to discover unusual patches of material on the tube walls. Whenever there was any question about a spot, the tube was turbined and re-examined, and if the spot persisted, the tube was removed for closer examination.

The last inspection was made in November 1946, after 20 months of nearly continuous operation at full load, and the tubes appeared to be in excellent condition. In order to be thoroughly assured that the telescopic examination was reliable, and to see if any small or incipient pits had formed during this period, five tubes, which had been in service since March 1945, were removed for

[3] "Measurement of Boiler Circulation by Means of Pitot Tubes," by T. Ravese, COMBUSTION, October 1944.
[4] "Thermocouples for Furnace-Tube Surface Temperature Measurements," by C. G. R. Humphreys, COMBUSTION, December 1944.

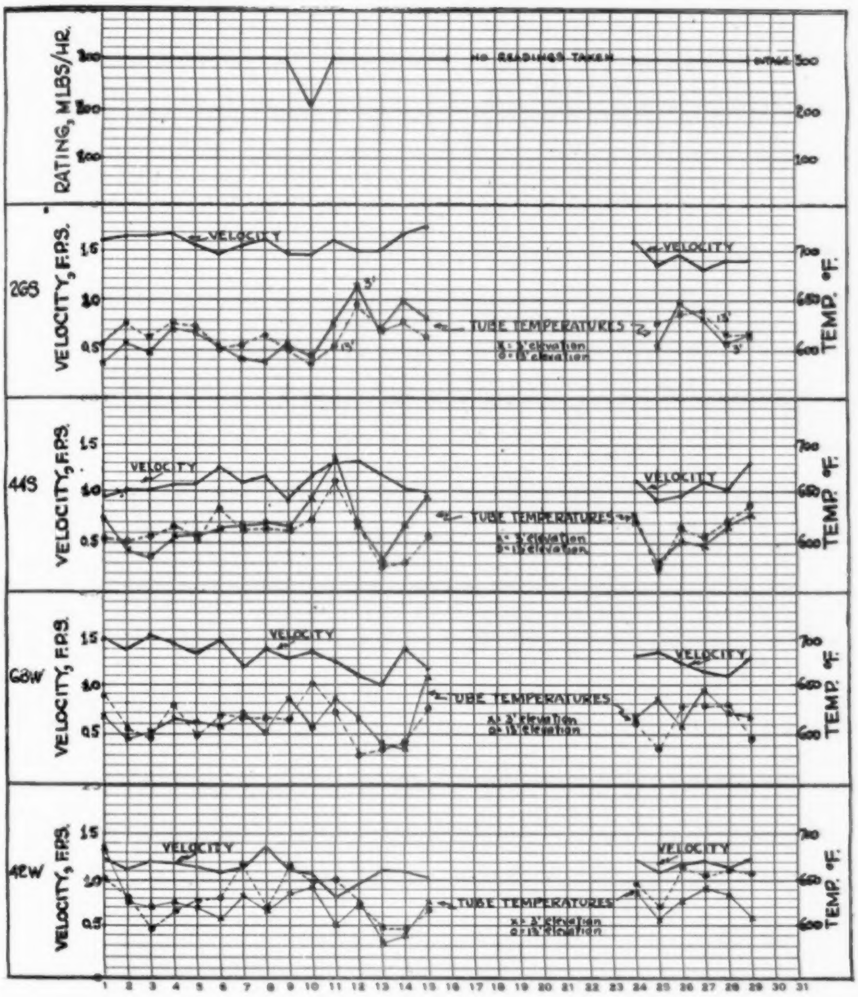

Fig. 2—Furnace tube temperatures and fluid velocity data from Firestone boiler

Fig. 4—Internal face of fire side of tube in service 67 days, showing deep pitting

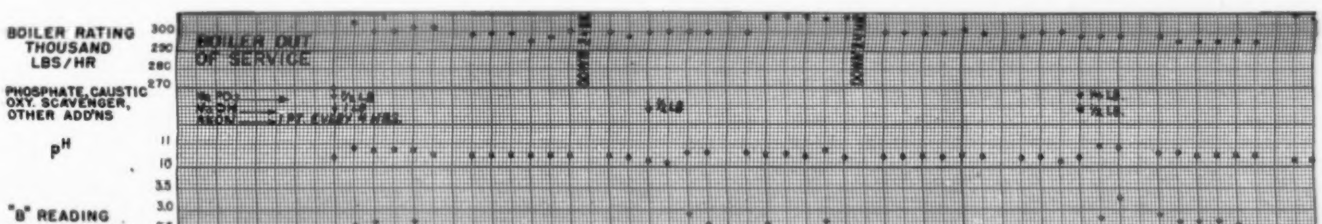

Fig. 3—Record of water analysis at Firestone covering two months

careful examination of the internal surfaces. The tubes selected were from areas where corrosion had been most severe. Four of these tubes were in perfect condition. The other was badly pitted, but in such a manner as to indicate beyond doubt that it had been corroded before it was installed, probably as the result of unfavorable storage conditions.

Therefore, when it is considered that prior to March 1945 new tubes had failed in as short a time as 67 days, it must be concluded that the corrective measures have been effective. Which single, or combination of these factors was effective cannot be determined, since all the changes were made simultaneously. One might infer that acid-washing, regardless of changes in the schedule of water treatment, was responsible for the improved conditions. But Hankison and Baker report that the failures at Springdale were *preceded* by frequent acid washes. It might be argued that the lower pH values, which at times were as low as 8.0, were responsible. But attack at Springdale occurred at above 11.0. This question of optimum pH for boiler and feedwater for low makeup, high-pressure boilers has not yet been established; possibly the optimum pH is a unique value for a given type of boiler. The writer has come to the conclusion that there is need for fundamental research work on the reactions of iron with pure water at elevated temperatures, in order to establish the minimum pH of feedwater that is required to effect adequate protection of steel surfaces under conditions of temperature, velocity, and concentration that are unique to boiler operation.

Explanation of Deep Pit

The tube shown in Fig. 4, which was in service at Firestone for only 67 days, prior to the time that corrective measures were taken, is of interest. The pit, so plainly seen, was $^5/_8$ in. in diameter, $^1/_8$ in. deep, and filled with a dense plug of Fe_3O_4. The microstructure very definitely showed evidence of intergranular attack that is associated with hydrogen diffusion in the grain boundaries at elevated temperatures. It was located in the furnace side of the tube, at an elevation of $9^1/_2$ in. above the swaged end, which places it about one inch below the top of the chrome ore floor; hence, at a point where the tube received no heat directly from the furnace. The average boiler water conditions during the time the tube was in service were as follows: pH = 9.5, B-reading = 0.3, PO_4 = 5.0 ppm, T.D.S. = 250 ppm, SO_3 = small excess. Surely this analysis would be considered adequate, yet rapid attack appeared to be indicated. The writer believes, although there is no definite proof, that at the time the tube was installed it had a small corrosion pit that formed during storage, and during operation the interior of the pit became progressively anodic and rapid attack ensued.

It is the writer's personal opinion that, for the most part, the tube damage at Springdale and Firestone was initiated by small spots of rust which formed in the tubes during times when high concentrations of oxygen were in contact with the metal, such as after drainage or after refilling with poorly deaerated and untreated feedwater. In the case of Springdale, where the unit was acid-washed frequently, the exposure of wet, freshly cleaned surfaces to the air after drainage afforded ideal conditions for incipient attack of the metal. Under ordinary operating conditions these spots would result in gradual formation of a pit, which might take several years to become serious, but under the high, sustained loads that such plants carried during the war, the corrosion processes within the pits were accelerated and damage quickly ensued. It seems to be more than mere coincidence that the number of tube failures was greatest during the last two years of the war at Firestone and Springdale, as well as at another, lower-pressure unit known to the writer.

When considering the action of boiler water on steel at high temperatures, sight should not be lost of the purely physical factors that operate between the metal and moving liquids and steam bubbles and the mechanism of bubble formation at high temperatures and pressures. Complementing the corrosion research, an intensive study should be made of the principal factors affecting boiling and foaming during steam generation.

Other Investigations

In 1941 Mumford, Markson, and associates,[5] studying heat transmission in boilers at 3000 psi, reported a parameter, ϕ, the ratio of the local rate of heat absorption to the mass flow and latent heat of the fluid, which determined the heat input required to overburden a tube with a given circulation rate. It was recognized by the authors that this parameter gave only a partial picture of the events occurring at the interface between the metal and the heat absorbing fluid. For example, practically nothing is known of the effect on heat transfer of such variables as the quality of the steam-water mixture, pressure, density, viscosity, surface tension, slip velocity, and the tube diameter, length, and thickness.

P. B. Place raised some cogent questions,[6] concerning the rôle of foam in steam generation, and suggested that we need to know more about the effect of foam on steam generating surfaces in preventing mixing of local films with the overall boiler water. Theoretically and experimentally it has been shown that pure distilled water does not foam and the tendency to do so increases with the concentration of the solute.

Larson,[7] in studies of the phenomena of liquid superheat and of nucleate and film boiling as a function of heat transfer, obtained interesting and thought-provoking results. For example, on a mild-steel ball as an ebullator he obtained 5 to 9 deg F superheat when the balls were previously phosphate-washed, 9 to 24 deg F when the pH of the liquid was adjusted to pH = 10 with NaOH, and 14 to 31 deg F when the water was saturated with $CaCO_3$ (pH 8.5). He concluded that substances known to be chemically inert or resistant to corrosion are not good ebullators and, therefore, support higher superheat. Further, his experiments suggest that the ability of a surface to initiate boiling in a superheated liquid depends primarily upon the adhesion free energy rather than physical roughness or porosity of the ebullators.

As problems, such as the one here discussed, continually arise, it becomes more and more apparent that fundamental chemical and physical research on problems related to steam generation has lagged.

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[5] "Studies of Heat Transmission Through Boiler Tubing at Pressures from 500–3000 Pounds," *Trans.* A.S.M.E., vol. 65, August 1943, pp. 553–591.
[6] *Proceedings* of the Sixth Annual Water Conference, Pittsburgh, Pa., p. 45.
[7] "Factors Affecting Boiling in a Liquid," R. F. Larson, *Ind. & Eng. Chem.*, vol. 37, 1945, p. 1004.

Factors Rarely Considered in Smoke Abatement

By HENRY F. HEBLEY

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JUST prior to World War II, there was ever-increasing growth in the social conscience of many communities which manifested itself in the demand for slum clearance, reduction of congested areas and smoke abatement. Then the war required an "all out" effort and the agitation for a reduction in the atmospheric pollution in centers of population were in abeyance during the emergency. With the cessation of hostilities, there has been a return to the consideration of the amenities of urban communities. This is evidenced by the great activity present in dozens of cities large and small in the demand for smoke abatement.

For the most part, those pressing for a cleaner atmosphere are intensely sincere in their efforts and firmly convinced that their particular solution of the problem is the only correct one and the only one to be adopted. This solution generally follows a familiar pattern:

1. Stress the need for smoke abatement legislation as a health measure.
2. Adopt the Ringelmann Chart as the standard for measuring the density of smoke emitted from a chimney over a stated period of time, in order to determine a violation.
3. Adopt a specification involving the weight of fly ash per cubic foot of flue gas and qualifying the particle size and the CO_2 content of the flue gas.
4. Adopt a so-called "volatile clause" that limits hand-fired boilers and heating equipment, both commercial and domestic, to the use of solid fuel that does not contain more than 23 per cent volatile matter on the dry basis. Such solid fuel is nominally classed in the coal trade as "smokeless."
5. Adopt a clause that makes it unlawful to import, sell, offer for sale, exchange, deliver or transport for use and consumption within the city limits or to use or consume within the city limits any solid fuel for hand-fired equipment that does not meet the definition of "smokeless solid fuel."
6. Adopt a clause requiring all truckers delivering solid fuel within the city limits to apply for a license and post a bond to insure the delivery of "smokeless solid fuel" to consumers using hand-fired equipment.
7. Provide a penalty that would forfeit the bond and cancel the license of any trucker who violates the provisions of No. 6 regarding the delivery of "smokeless solid fuel."

Brief mention of this paper, presented at the 1946 A.S.M.E. Annual Meeting, was contained in COMBUSTION's report of that meeting in the December issue. Since then, agitation for smoke abatement and curtailment of atmospheric pollution has sprung up in several eastern cities, including New York and Syracuse. It is important that many of the factors mentioned by Mr. Hebley be investigated locally before adopting preventative measures, for which reason the paper is being reproduced nearly in full.—EDITOR

Many other clauses are adopted pertaining to inspections—approval of new installations, permits, fees, etc., but for the purpose of this text, they will not be considered. The seven points enumerated form the salient factors.

The strategy adopted in pressing for enactment of smoke abatement laws is to urge it as a health measure. It is felt that the law will then have a better chance of withstanding attacks on its constitutionality.

In all public hearings regarding this problem, the evidence also follows a similar pattern:

1. Medical testimony is offered indicating the prevalence of diseases of a respiratory nature in urban populations where smoke in the atmosphere is considered excessive. The common cold, pneumonia and sinus infections are noted and the strength of the correlation between dust fall and deaths from pneumonia, tuberculosis, etc., is expressed by presenting correlative coefficients. Less emphatic statements are presented to the effect that lack of sunshine (ultra-violet rays) contributes to a general lowering of the populace's health, and is in part responsible for the depressed feeling experienced on murky days—even to the extent of suicides.
2. The influence of the smoke problem on the cost of living is presented in testimony on the cost of cleaning, painting and decorating, laundering, the maintenance of buildings, etc.
3. The impairment to flora in urban centers, brought about by smoke-laden atmosphere.

The whole matter becomes highly controversial and the original aim, namely, to reduce the amount of atmospheric pollution in urban areas, becomes lost. Such a result is unfortunate as no matter which group is successful, it is of little help if the solution advocated fails.

Dust or Soot Deposits

One of the usual methods of attack on the problem of smoke is to set up sampling stations for the collection of deposits settling out of the atmosphere.

The weight of the depositions is generally computed on a monthly basis and from these results the deposition is projected to tons per square mile. Sometimes samples of the collected material are analyzed. Such analytical work varies from comparatively routine to a rather elaborate procedure including:

Insoluble matter:
- Tar
- Carbonaceous other than tar
- Ash

Soluble matter:
- Loss on ignition
- Ash

Included in soluble matter:
- Sulphates (SO_3)
- Chlorine (Cl)
- Ammonia (NH_3)

These results of the monthly deposits in tons per square mile are often used in correlation with respiratory diseases to indicate the strength of the influence of deposits on health. Unfortunately, little or no planning of the investigation is adopted and the variables existing make the reliability of the results open to question. For instance, in the heart of a city with "sky scrapers" standing next to four- or five-story structures or to parking lots, the elevation of the deposit gage is a factor. Placing the receptacle at street level may be influenced by purely local conditions and the observations may be vitiated by vandalism. The shelter that may be afforded a gage by the proximity of a building has been known to make the observations worthless. If the deposit gage is located in a park or open space, the influence of the filtering effect of trees, shrubs, etc., is related to the position of the gage in relation to the borders of the park.

As pointed out in the scientific survey of the atmospheric pollution in the city of Leicester by the Department of Scientific and Industrial Research (1) some of the differences encountered between the determinations of a certain deposit gage in two consecutive months are brought about by:

Wind direction
Atmospheric turbulence—both dynamic and thermal
Humidity
Rainfall
Seasonal variations
Irregular variations
Other miscellaneous factors

Thus it leaves the investigator with so many factors obscured that the problem of analyzing and interpreting the data collected becomes extremely difficult.

Many of the data dealing with dust and soot fall that have been presented at public hearings have been invested with an accuracy and reliability which, when analyzed, is quite misleading. To associate them statistically with the number of deaths from pneumonia or tuberculosis and report the relation to the extent of correlation coefficients is unwarranted. The use of "correlation coefficients" should be practiced with judgment.

There is also a tendency to draw conclusions based on samples that are entirely inadequate and covering periods of time that are far too short. The Department of Scientific and Industrial Research, in their investigation of Atmospheric Pollution, use the average of monthly observations of at least five consecutive years for a basis of comparison in which confidence can be placed. The monthly deposits recorded for any single year when compared to the five years may show great deviation, probably brought about by the variables previously mentioned. A glance at these will indicate that weather influences predominate.

It is desirable, therefore, that the modern climatologist, skilled in the new techniques developed during the last five years, become closely associated with the planning and execution of any investigation involving the variable influence of the weather, and its effect on air pollution. So far as can be ascertained, the skill of these technologists have not been called upon.

In further consideration of the analysis of the deposit observations, there are two other factors that will bear some thought, namely:

1. The area of influence, contributing to the matter deposited in the collection gages.
2. The area assigned to a deposit gage, whose weight of collected material will be projected in tons per square mile of that area.

The first item requires consideration of the source of the material deposited in the gage. So far these points of origin have not been definitely placed and there is even great uncertainty regarding the location. Studies have indicated that when the material deposited is divided into insoluble and soluble matter, there seems to be some relationship between the amount of rainfall and the amount of soluble matter deposited (1).

Such a relationship suggests the possibility of clouds carrying considerable soluble matter, and also of the raindrops washing some of the impurities out of the atmosphere as they fall.

The direction of the wind and its velocity may contribute to the deposit gages material from distant areas. Brotzman (2) has stated that given a wind velocity of ten miles per hour, air pollution originating at Youngstown, Ohio, at say midnight, can be over the Pittsburgh area the next morning while that city's pollution will be carried to some other section. The well-known experience will be recalled that during the periods of the dust storms in the Western prairie states, air borne dust was deposited along the eastern seaboard. As a matter of fact, the climatologist depends on the analysis of this air-borne dust to type it for origin.

The second item is also an important matter. The deposit gage has a collecting funnel 12 in. in diameter or 0.78 sq ft. It is on this area that the tons per square mile are predicated. If the determination of one gage is projected to this area, the ratio is 1:35,000,000. Such a small sample requires that the greatest skill be exercised in the selection of the gage location, striving to place it in an area that is quite uniform and free from a concentrated local pollution.

It is quite possible that greater accuracy could be attained through the use of a number of smaller receptacles placed uniformly over the area, averaging the deposits collected and analyzing a composite sample.

Every effort must be made to avoid too elaborate procedure calling for a great volume of analytical work. Such a method generally involves great expense and effort and the work is abandoned before a long enough period has elapsed to yield to confidence in the results.

In addition to the material collected in the deposit gages, there is the great amount of pollution that is held in suspension in the atmosphere. It is composed of a number of materials—particles of carbon, plant spores, dust, fumes, mist, fog and the gases of combustion including smoke.

The Ringelmann Chart

In the United States practically the only measure that is adopted for measuring such suspended impurities is the Ringelmann Chart. It can only be applied to flagrant cases of air pollution as it depends on a visual estimate of the color of the products of combustion being emitted from the chimney under observation. It is a convenient measure for the personnel of the Smoke Abatement Department of any city to use; but the data yielded by the observations are inadequate if the aim of any municipality is to gain a measure of its atmospheric pollution in order to reduce it. Marks (3) has already drawn attention to its weak points, although for some reason not known, this criticism has not received its proper consideration. So far as can be ascertained, the selection of smoke inspectors does not require any close examination of their eyesight. The task of inspecting a chimney is essentially one of matching the shade of the smoke emitted, with a set of standard charts.

The late Dr. J. S. Owens (4), in calibrating his scale of shades for the automatic filter recognized the limit of sensitivity of the eyes and made a study of the error involved. He states: "As the error in reading shades is a fraction of the brightness, and this depends on the proportion of white in the shade, its reflection factor, and illumination—the effect of the two latter (must be) considered."

Individuals familiar with the use of the chart are aware that the percentage of the white area varies inversely with the Chart number:

RINGELMANN CHART

Chart No.	% White	% Black
0	100	0
1	80	20
2	60	40
3	40	60
4	20	80
5	0	100

With this qualitative measure one even encounters inspectors who discuss the shade reading to the nearest tenth. Such factors as wind velocity, diameter of stack, position of observer, background, and illumination have a noticeable influence on the shade reading.

The chart has another great limitation. It can only be employed during the hours of daylight. If atmospheric pollution in suspension is going to be analyzed in a rational manner, a quantitative measure of that pollution should be adopted. The impurities may be expressed in milligrams per cubic meter, under standard conditions or some other convenient basis. In addition, the sample should be drawn throughout the 24 hr of the day.

It has been found, based on a recent survey of the city of Leicester (1), that all of the sampling points measuring suspended matter have shown on one day, five or six times as much impurities as on the following day. A possible explanation for this great variation is the degree of turbulence experienced in the atmosphere from day to day. Because of these factors, the conclusions regarding the reduction of air pollution due to the steel strike did not show any strong significance in the statistical sense.

Another comparison for the same period was made, based on the visibility observations of the Pittsburgh Station of the U. S. Weather Bureau. The visibility readings for the period of January 28 to February 17 were studied for each of 16 consecutive years.

There was a slightly improved visibility record for the 1946 period; but when the other influencing factors are considered, the improvement was not strongly significant.

In 1918, the late Dr. J. S. Owens developed an automatic filter designed to draw regular samples of air from the atmosphere at the rate of approximately two liters per hour. The air is passed through filter paper leaving a stain one inch in diameter. Calibration of the stain with unit weight per unit volume was carried out with great care and precision, giving a measure that could be reported in milligrams per 100 cubic meters. For a description of the method of calibration of the automatic filter, one may refer to the work of J. G. Clarke, "Atmospheric Pollution Annual Report No. 3," 1916–1917.

A further development of the measure of suspended impurities in the atmosphere is the smoke filter in which an air pump draws a sample of air throughout the day

and passes it through a filter and subsequently to an absorbtion bottle for volumetric SO_2 determination and a dry-gas meter for air volume determination.

A calibrated photo cell equated to direct weighings of samples of impurities filtered from the atmosphere is used in conjunction with a galvanometer to measure the light passing through the stained filter. The results are reported in milligrams per cubic meter.

Little work has been done in the United States following this method of investigation. The procedure, however, introduces a new aspect to the problem. That is, the concept of air volume in atmospheric pollution. Impurities in suspension are related to the cubic measure of the atmosphere.

Until comparatively recently, most weather forecasting was carried on from the ground and little investigation was made of conditions aloft. The growth of air travel especially during the war made the study of atmospheric conditions, including the third dimension, imperative. A similar approach is essential in the investigation of atmospheric pollution. In recognizing this influence as associated with the volume of air enveloping and spread above a center of population, there are a number of factors to be given consideration.

Wind velocity is important. According to H. Landsberg (6) cities of large dimensions tend to reduce wind velocities compared to the rural areas that surround them. The ability of wind to carry air pollution for many miles is well known and it is that action that has encouraged man to discharge his products of combustion to the atmosphere, hoping that wind movement will scavenge the impurities and send them elsewhere.

Apart from wind transport, there is the very important influence of turbulence. Eddy currents varying from, say, a few feet to miles in diameter and experiencing vertical movements as well as those of translation, are dominant factors in changing the concentration of impurities in the atmosphere. The turbulence may be dynamic in nature, caused by the energy contained in the air masses. In addition there is the vastly important thermal turbulence that is experienced. This influence on the impurities in the atmosphere cannot be over-estimated. The atmosphere of a city is never completely at rest throughout any 24-hr day; and the variation in the turbulence will bring about rapid changes in the quantity of air pollution, as the eddies cause an exchange of polluted air from below with the clean air above. How frequently has it been observed that on one day the air is polluted and on the following one it is clean. Yet there has been no great change in the fuel used in the area. The action of turbulence in relation to urban air pollution is not properly understood at present and a great deal more investigation is required.

Temperature Inversion

The association of strong winds with low barometric pressure is well known. It is also a fact that the frequency of passage of such lows are greater in winter than in

summer, so that the average wind velocity is higher in winter than in summer. Yet the air pollution is generally greater in winter. This is due to the effect of another factor, namely, the stability of the air. Air is stable when the colder air underlies the warmer air. This is inversion.

If the third dimensional study of the atmosphere in relation to air pollution is continued, the influence of the phenomenon of inversion of the temperature gradient of the atmosphere will be found to be of importance. Under normal conditions, the temperature of the atmosphere is lowered with increasing altitude at the approximate rate of 1 deg F for each 300 ft of elevation. When this relationship is in effect, warm air adjacent to the ground will obey the tendency to rise to be replaced by cold air, thus setting up convection currents and turbulence. There are times, however, and they occur more frequently than realized, when the normal temperature gradient becomes inverted. In other words, there is a stratum of air at a certain elevation which has a distinctly higher temperature than the layers of air below it. This is the condition of stability previously noted. Such a stratum effectively acts as a ceiling or lid to imprison the impurities released by any center of population.

Under such stable anticyclonic air conditions with but very slight turbulence, inversions have been known to last for days, sometimes with disastrous results. Probably the best known example of recent years was the tragic event experienced in the Meuse Valley in December 1930. Stable air at high barometric pressure and practically no turbulence was present for a number of days. The city of Liege (Belgium) dominated by heavy industry is situated on the river Meuse. The narrow valley of the river adjacent to the city became filled with the gases of combustion released from the factories of Liege because of a temperature inversion encountered at the low level of 270 ft above the bottom of the valley. The condition persisted for four days, during which time there were hundreds of cases of respiratory attacks with 63 deaths occurring on December 4 and 5. Numerous cattle had to be slaughtered. The inversion conditions disappeared December 6, and the respiratory attacks abated. Subsequent investigation indicated that the primary cause was the presence of sulphuric acid formed from SO_2 released in the products of combustion (7).

Inversions may be conveniently classed as low and high. The example cited would be classed as low, and the gases of combustion released from chimneys are kept down close to the ground causing murky conditions at building levels and in the street.

If the stratum of warm air is at a high level, then the impurities associated with the gases of combustion are lifted well above the tops of the buildings, but will accumulate as a heavy black layer that effectively prevents daylight from penetrating and causing darkness in the city forcing the use of light in homes and offices and headlights on automobiles and street cars. Such an inversion was experienced in Pittsburgh at 4:00 p.m., November 11, 1946.

If inversion conditions continued for a sustained period of time, the amount of solid impurities being emitted by the chimneys of a city would ultimately reach a state of equilibrium with the amount of deposition equaling the solids discharged. However, the atmosphere would become intolerable, not because of the visible particles (smoke) but because of the infinitely greater amounts of noxious gases of combustion that carry those particles; namely, the sulphur dioxide (SO_2) and carbon dioxide (CO_2).

These gaseous products of combustion, invisible though they are, form the basis of the air pollution associated with industrial centers. They cannot be over-rated, as on the average there are at least 50 times more of these gaseous particles of combustion in the atmosphere than there are solid (smoke and dust) particles.

Fly Ash

With the development of the art of burning pulverized fuel in suspension, the problem of particles of ash being discharged from the stack into the atmosphere has become increasingly serious. Due to the method of firing, combustion is practically complete with the result that the fly ash particles are composed of inert matter—silica, alumina, etc. The particles vary in size from those that fall to the ground quite rapidly, to those that are borne for miles on the wind and air currents that pass by the chimney.

Efficient mechanical and electrostatic dust collection equipment is available to meet the requirements of any of the existing clauses limiting fly ash emission. The clauses, however, generally adopt the A.S.M.E. Tentative Method of Testing Dust Collection Apparatus as part of the ordinance, by reference, with little or no knowledge of the requirements contained in those test methods and no knowledge of the practical difficulties involved, nor of the problem of obtaining a representative sample, nor the cost of such a test. In one proposed ordinance recently prepared, it contained a clause applying the A.S.M.E. Methods of Test to locomotives in operation. Fortunately, wiser and more experienced counsel prevailed and the section was deleted. The particles of ash and carbon that are emitted and held in suspension in the air represent approximately 2 per cent of the total amount of material held in polluted air. According to modern climatological research, dust and smoke particles are classified as inactive. In other words, they ordinarily do not interact with the water vapor in the air and take little or no part in the condensation processes in the atmosphere that led to haze and fog.

Condensation Nuclei

Two kinds of suspensions pollute the atmosphere:

1. Dust, and that includes sand, carbon particles, ashes, rubber from tires, clay, brick, etc.
2. Condensation nuclei, which, due to their chemical nature, attract water vapor from the air to form minute, visible or invisible droplets.

The condensation nuclei play an important role in the formation of fog, haze, clouds and rain. In the free atmosphere the nuclei present the surfaces on which the vapor condenses. These nuclei themselves are invisible to the naked eye and can be made visible only in the electron microscope when magnified many thousand times.

The long list of condensation nuclei is headed by sulphur dioxide, which, under the influence of sunlight, turns into sulphur trioxide, and with its associated water vapor from the atmosphere forms sulphuric acid. Sulphuric acid is responsible for much of the corrosive effects on city structures; it is also the cause of the irritating and biting sensation in the throat. Other substances acting as nuclei are nitrous and nitric oxides, phosphorous and common salt. The chief "man made" sources of nuclei are industrial furnaces and processes of all kinds, such as blast furnaces, bessemer converters, open hearths, rolling mills, coke ovens and all industrial and domestic chimneys. In addition, there are the transportation facilities, such as steam and diesel locomotives, steam and motor boats, trucks, automobiles and airplanes. In short, all combustion processes—no matter whether the fuel be solid, liquid or gaseous, will contribute nuclei.

These condensation nuclei abound in the atmosphere; and even in the purest country air, sufficient nuclei are always present to produce fogs, if the general large-scale weather conditions are conducive to it. There is always an excess of nuclei present in the air, so that even in the densest fog there are a great many nuclei which have not taken part in the condensation process.

In regard to the diesel engine, it has been found that the cleanest diesel exhaust contains many condensation nuclei.

The air pollution problem in cities and industrial areas is not solely concerned with the visible nuisance caused by smoke and dust. The over-whelming excess of nuclei and their relationship to the ever-changing weather conditions represents a much more complex and important aspect of the problem.

Industrial areas and large cities are copious producers of particles that present surfaces for the condensation of atmospheric moisture. In addition, such areas are usually located in the vicinity of water surfaces for convenient transportation. In that regard, the spray from the sea contributes quantities of particles of salt that act as condensation nuclei.

While fog formation is facilitated by the presence of abundant nuclei and of water vapor, other large-scale factors such as wind, temperature distribution with elevation, etc., must fulfill certain conditions before actual fog will form. If these conditions are fulfilled, then fog will form at an earlier hour and last a longer period of time in industrial areas than at localities where pollution is relatively small. The reason for this ease of fog formation and its persistence is of interest.

In air of low relative humidity, the hygroscopic condensation nuclei, originally extremely small solid, liquid or gaseous particles, attract water vapor in which they dissolve to form an invisible droplet of a salt or acid solution. With an increase in relative humidity up to approximately 70 to 80 per cent, the droplets at first grow slowly. At relative humidities above 80 per cent the rate of droplet growth is more rapid and the droplets finally become visible.

In pure country air, fog will not become visible until a 100 per cent humidity has persisted for some time, as the relatively few droplets must grow to a considerable size before they have an appreciable effect on the transparency of the air. On the other hand, in industrial areas, haze and fog becomes apparent at relative humidities far below the saturation point, as a large number of small droplets greatly reduce the transparency of the air.

There is no material difference between nuclei, haze and fog, the only distinction being the degree to which the transparency of the atmosphere is reduced by the suspended droplets. If dust or particles of carbon are mixed with the fog, the so-called "smog" results and the visible conditions of pollution are aggravated.

In an industrial area, the condensation nuclei composed of sulphur dioxide are among the most serious. The Meuse Valley tragedy (7) was caused mostly by the sulphuric acid formed from these combustion products. So far, however, none of the ordinances that have been adopted have shown any realization of the complex problem confronting communities in abating the air pollution. Clearly, the Ringelmann Chart is inadequate as a measure of the factors described.

In addition, it would be advantageous to know the pH value of the rain and possibly fogs and clouds over an industrial city. The CO_2 present in an industrial atmosphere is generally accepted as bringing the pH value of rain to 5.5. However, some rain has shown a considerably lower value.

The use of low-volatile coal, while undoubtedly easier to burn without releasing quantities of smoke that would violate an ordinance, would still not overcome the fog-producing condensation nuclei. A glance at Johnstown, Pa., and Charleston, W. Va., where the domestic fuels are low-volatile coal and natural gas, respectively, will indicate that given the right weather conditions the air pollution present will aid in forming fog.

What is actually needed is a modern research program in atmospheric polution.

In closing, the author wishes to express his thanks and appreciation to Dr. Hans Neuberger, Professor of Climatology, Pennsylvania State College, for his invaluable assistance in the preparation of this text.

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Deliveries of Large Turbine-Generators

In view of the present unprecedented activity in utility construction, deliveries of large turbine-generators and electrical equipment for central stations are subject to considerable delay. A typical statement of the situation is contained in the recent announcement of Tomlinson Fort, Manager of the Westinghouse Central Station Sales Department. Despite greatly enlarged production facilities, he states that scheduled deliveries of turbine-generators above 10,000 kw are such that those purchased now cannot be put in service until the second half of 1950. For capacities below 10,000 kw the schedules are not filled that far ahead.

Large motors for auxiliary drives now require 15 to 20 months for delivery and smaller motors can be shipped in 3 to 8 months less time. There is great need for proper coordination between ordering of the turbine and the auxiliary motors so that the latter will not form a bottleneck in getting the new unit in service.

A two-year backlog of unfilled orders exists on assembled metal-clad switchgear, and delivery time on orders for large outdoor oil circuit-breakers is 18 to 28 months. For power transformers above 12,500 kva the shipping schedule is 21 to 26 months and 19 to 22 months for smaller sizes.

With reference to turbine-generators, Mr. Fort stated that the delivery situation could be aided greatly if more orders followed the A.I.E.E.-A.S.M.E. recommended standards for unit sizes of 11,500 to 60,000 kw. He pointed out that most manufacturing plants today are geared to quantity production and that wider use of standard designs would not only aid deliveries but would also tend to prevent further price increases.

Research and Development Aided by Department of Commerce

Although established some months ago, the research and development facilities afforded to industry by the Office of Technical Services, Department of Commerce, have not been widely publicized. The purpose and procedure, as outlined in a memorandum issued January 7, 1947, is to initiate and conduct applied research and development of inventions, processes, mechanisms, etc., that hold promise of usefulness and benefit to industry, large and small, by promoting and encouraging technological advances, creating new and improved products and increasing employment.

The research fund, created by the last Congress and administered by the Industrial Research and Development Division (IRDD) is open to all industry, and contracts for research projects which meet the requirements are to be placed with universities and private industrial research laboratories.

The patent policy provides the contractors, inventors and their co-workers with maximum incentive to invent and present ideas through the use of government funds, inasmuch as the inventor will be permitted to retain ownership of any invention resulting from the research, subject to the usual royalty-free license for Government use. If he wishes to apply for patents this will have to be done at his own expense. He will also be required to grant licenses, on reasonable terms, to other applicants for use of any inventions resulting from the contract.

Before undertaking a contract the Government is supposed to investigate its merits and probable success, for which purpose a Review Board has been created. Moreover, the IRDD will assist in finding a market for the invention and take the initial steps to establish it industrially.

Finally, the inventor of a successful project is required to return to the Government the sum of money that is properly chargeable to the part of the contract that was directly responsible for the invention. Payments are to be made as a percentage of the industrial profits and receipts from royalties until the required amount is returned.

Record Peak Loads

Major electric utility system peak loads for December 1946 set an all-time high of over 43 million kilowatts, according to figures compiled by the Federal Power Commission. This figure is 14 per cent higher than that of December 1945; it exceeded the wartime high by 12.9 per cent; and by a substantial margin set a new record. Corresponding energy sales for December amounted to 20,432,207,000 kwhr which was also a record maximum, representing a gain of 14.4 per cent over December 1945.

A.S.H.V.E. Meeting

Announcement has been made that the American Society of Heating & Ventilating Engineers will hold its Semi-Annual Meeting June 2 to 4 at the Hotel del Coronado, Coronado, Calif. The Southern California Chapter of the Society will act as host for the occasion.

Personals

Erling Klafstad, for the last 18 years chief engineer of Crosby Steam Gage & Valve Company, has been elected vice president in charge of operations and engineering.

George W. Kelsey, general sales manager of Builders Iron Foundry for several years past, has been named a vice president of that company.

E. A. Weber, who has been associated with the New York Office of Refractory & Insulation Corporation for over five years, has been made sales manager of distributors for that company.

Harold V. Rasmussen has recently been appointed chief engineer of the turbine department of DeLaval Steam Turbine Company; **Harry Engvall,** chief engineer of the helical gear department; and **Hans Gartmann,** chief engineer of that company's centrifugal pump and compressor department.

Martin Meyer has been made assistant sales manager of Sauerman Bros., Inc., Chicago.

G. C. Derry, vice president and general manager of B. F. Sturtevant Company was elected vice president of the National Association of Fan Manufacturers at its Annual Meeting on February 12–13.

EQUIPMENT SALES

as reported by equipment manufacturers to the Department of Commerce, Bureau of the Census

Boiler Sales

Stationary Power Boilers

	1946 Water Tube		1945 Water Tube		1946 Fire Tube		1945 Fire Tube	
	No.	Sq Ft*	No.	Sq Ft*	No.	Sq Ft	No.	Sq Ft
Jan.....	173	1,109,924‡	96	534,669	113	154,064	50	60,710
Feb....	197	1,262,520	101	481,726	126	171,100	75	99,815
Mar....	171	1,357,650	134	759,214	123	180,532	77	87,266
Apr....	198	1,247,693	85	422,213	110	137,614	78	99,154
May...	158	980,004	125	812,989	86	117,554	81	83,285
June...	151	980,231	186	1,266,372	99	157,664	90	106,085
July...	191	1,469,638‡	200	1,013,156	88	97,276	88	134,714
Aug ...	128‡	877,497‡	152	853,758	117	147,684	105	139,936
Sept....	136	1,207,409	150	1,000,878	73	94,164	99	128,948
Oct.....	187	1,591,936	147	823,329	92	104,434	120	149,768
Nov....	150	1,043,988‡	157	804,089	73	70,332	98	126,425
Dec....	159	1,067,988	160	1,051,240	81	79,804	117	147,974
Jan.–Dec., incl..	1,999	14,196,478	1,693	9,842,998	1,181	1,512,222	1,078	1,364,080

* Includes water wall heating surface. ‡ Revised.

Total steam generating capacity of water tube boilers during the period Jan. to Dec. (incl.) 1946, 137,457,000 lb per hr; in 1945, 89,466,000 lb per hr.

Marine Boiler Sales

	1946 Water Tube		1945 Water Tube		1946 Scotch		1945 Scotch	
	No.	Sq Ft*	No.	Sq Ft*	No.	Sq Ft	No.	Sq Ft
Jan.......	2	11,276	335	1,400,000	1	590	6	1,073
Feb......	—	—	34	178,726	—	—	5	1,186
Mar......	—	—	49	193,124	4	1,706	10	7,685
Apr......	18	46,390	16	65,252	1	263	4	2,126
May.....	4	9,040	22	100,362	1	263	2	526
June.....	31	17,620	21	114,537	1	520	22	7,605
July.....	2	7,424	47	249,663	3	539	12	3,352
Aug......	—	—	39	133,420	16	5,087	5	1,221
Sept......	5	11,836	34	3,802	1	990	1	427
Oct.......	—	—	2	22,720	—	—	4	2,809
Nov......	—	—	6	23,975	—	—	1	520
Dec......	4	7,550	8	37,600	2	611	3	997
Jan.–Dec., incl.....	66	111,236	613	2,523,181	30	10,569	75	29,527

* Includes water wall heating surface.

Total steam generating capacity of water tube boilers sold in the period Jan. to Dec. (incl.), 1946, 1,023,000 lb per hr; in 1945, 29,503,000 lb per hr.

†Mechanical Stoker Sales

	1946 Water Tube		1945 Water Tube		1946 Fire Tube		1945 Fire Tube	
	No.	Hp	No.	Hp	No.	Hp	No.	Hp
Jan......	61	35,757	42	18,990	184‡	23,323‡	187	25,299
Feb......	71‡	40,880‡	57	22,510	175	27,708	162	20,565
Mar......	94	45,646	87	32,451	181	28,071	233	32,447
Apr......	93‡	45,606‡	57	21,004	249‡	42,271‡	197	27,358
May......	101	49,653	101	40,470	202	30,933	240	32,456
June.....	76	42,259‡	78	33,644	233	32,815	249	34,183
July.....	97‡	50,668‡	160	71,025	233	33,290	265	34,286
Aug......	72	30,101	348	43,182	355	40,716‡	98	40,309
Sept......	49	28,118	333	44,938	401	34,937	95	45,147
Oct.......	77	36,320	—	—	377	42,134	367	51,493
Nov......	64	34,787	70	31,295	293	23,708	330	45,225
Dec......	50	27,815	67	31,448	288	21,468	264	31,932
Jan.–Dec., incl.....	905	467,610	1,400	390,957	3,171	381,374	2,687	420,700

† Capacity over 300 lb of coal per hour. ‡ Revised.